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REFRIGERATION IN THE HANDLING, PROCESSING, AND STORING OF MILK AND MILK PRODUCTS

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INTRODUCTION

Refrigeration in the dairy industry has made great advance in the past decade. Even more progress might have been made if more owners and operators of dairy plants had been fully aware of the many advantages of the proper use of refrigeration, and if the manufacturers of refrigerating machinery generally had been sufficiently familiar with the special conditions existing in the dairy industry to design equipment best adapted to them. This publication, therefore, should be of service both to those engaged in the dairy industry and to the manufacturers of refrigerating machinery. In it are discussed the various applications of refrigeration in the operation of the modern dairy plants and the methods most commonly used in the latest and best equipped plants. The term " dairy plants " is here used in its broadest sense and covers all plants that handle milk or manufacture milk products.

MECHANICAL REFRIGERATION

UNIT OF REFRIGERATION

The unit of refrigeration represents the heat absorbed in melting 1 ton (2,000 pounds) of ice at a temperature of 32° F. into water at the same temperature. It is the latent heat of fusion of 2,000 pounds of ice, or 288,000 British thermal units. The capacity of a refrigerating machine is based on continuous operation for 24 hours. Thus, a 1-ton refrigerating machine has a capacity sufficient to extract 288,000 British thermal units per 24 hours, under standard conditions—that is, when operating at a suction temperature of 5° and a discharge temperature of 86°.

THE COMPRESSION SYSTEM OF REFRIGERATION

Modern refrigerating systems are based upon the alternate vaporization and condensation of some volatile liquid. Low temperatures are produced by utilizing the latent heat of vaporization; the alternate condensation is merely to salvage the refrigerant and change it back to liquid form in order that it may again be evaporated. In Figure 1, the drum contains some volatile liquid—ammonia, for example—which is allowed to escape to the air through the coils in the brine tank. The ammonia will boil at a temperature of −28° F. The latent heat of vaporization will be absorbed from the brine, which will be cooled rapidly since each pound of ammonia evaporated will absorb 588.8 British thermal units. The simple arrangement illustrated, however, wastes the vaporized refrigerant and therefore would be too expensive to be practicable.

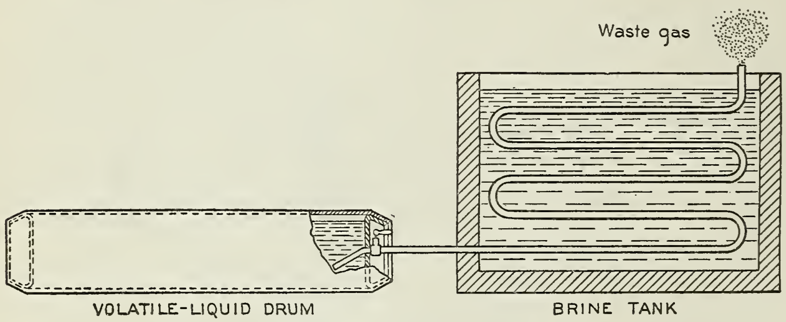

FIGURE 1.—Elementary refrigerating system

To utilize its latent heat of vaporization for refrigeration and to conserve the refrigerant, application is made of the physical law that the temperature at which a fluid boils or condenses is raised or lowered, respectively, by increasing or reducing the pressure. To cause the refrigerant to boil at a low temperature in the evaporating coils and hence absorb heat on a low-temperature plane, the pressure in the coils is lowered by the suction of the compressor. (Fig. 2.) To free the fluid of the heat absorbed in the refrigerator and return it to liquid form, the cold refrigerating gas coming from the evaporating coils is compressed until its temperature is raised above that

of the water flowing through the condenser so that the contained heat can pass from the gas to the water. (In very small machines, air may be used instead of water.)

The essential parts of a compression-refrigerating system are an evaporator, a compressor, and a condenser.

In the evaporator (the coils in the refrigerator) the liquid boils and in the process absorbs heat from the surrounding medium. The compressor is a specially designed pump that takes the gas from the evaporator coils and compresses it into the condenser coils, reducing its volume and increasing its temperature. The condenser consists of coils of pipe over or through which water or air flows to absorb the heat from the gas, which is thereby liquefied. In some systems the cooling water passes through an inner tube, and the gas from the compressor through the annular space between the inner

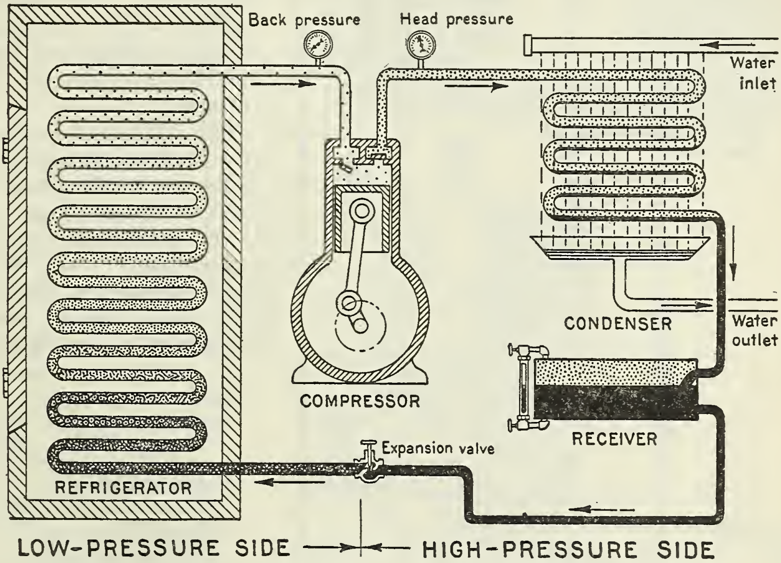

FIGURE 2.—The essential members of a compression-refrigerating system

and the outer pipes. From the condenser the refrigerant passes first to a liquid receiver, and then through a throttling or expansion valve into the evaporator coils, to repeat the process of transferring heat from the refrigerator to the water flowing through the condenser. The temperature of the liquid ammonia is reduced from the temperature of the receiver to that of the refrigerator by vaporizing a part of the liquid.

The expansion valve is of a special design and is capable of very fine adjustment. Its function is to so regulate the flow of the liquid refrigerant that suitable pressure and temperature conditions will be maintained. It is largely responsible for the control of temperature in the evaporating or cooling coils.

Figure 3 shows the layout of a complete compression system with all accessories, including piping, valves, oil trap, strainer, high and low pressure gauges, and by-pass connections.

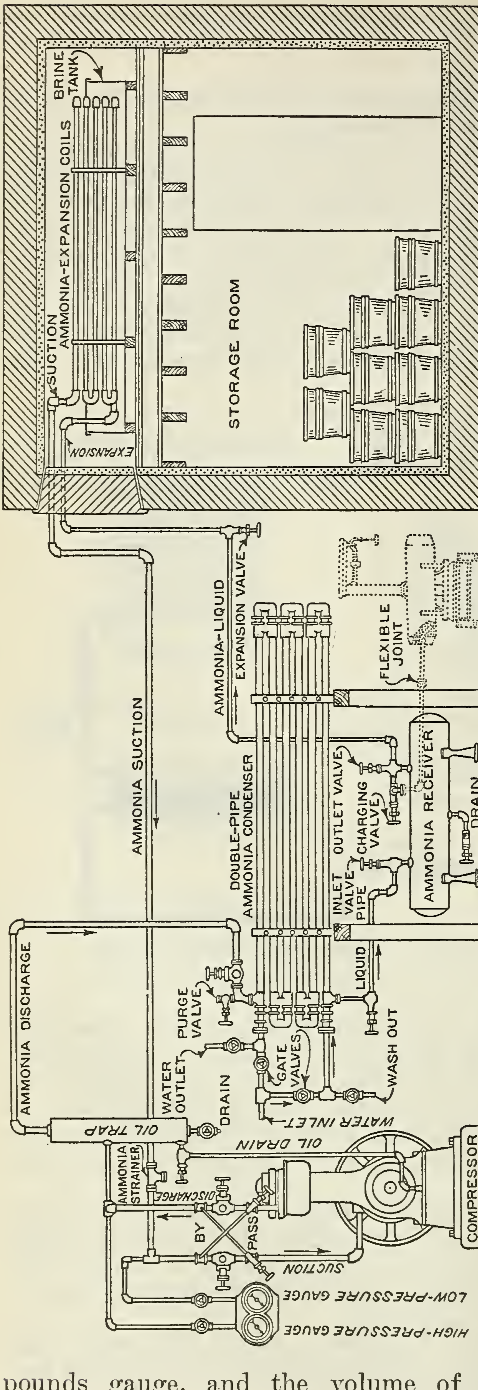

FIGURE 3.—General arrangement of a complete compression-refrigerating system

CAPACITY

The capacity of a compression refrigerating machine decreases with the lowering of the back or suction pressure, other factors remaining the same, because the density of the gas becomes less as the pressure is reduced, and the compressor, at a given speed, will handle a smaller weight of gas per minute. The refrigerating effect depends on the weight of gas handled and not on the volume.

The standard rating of a refrigerating machine is based upon a suction temperature of 5° F. and a condenser temperature of 86°. For ammonia as the refrigerant, under these temperature conditions.

	B. t. u.
Heat in 1 pound saturated ammonia vapor at 5° F	613. 3
Heat in 1 pound liquid ammonia at 86°	138. 9
Refrigerating effect of 1 pound of ammonia	474. 4

Since 1 ton of refrigeration per day is equivalent to the removal of 200 British thermal units per minute, the weight of refrigerant that must be circulated and evaporated per minute is $200 \div 474.4 = 0.422$ pound per ton daily capacity.

The pressure corresponding to a temperature of 5° F. is 19.6 pounds gauge, and the volume of gas is 8.15 cubic feet per pound. The volume of gas that must be handled per minute, there-

fore, to produce 1 ton of refrigeration under standard conditions, is 5,944 cubic inches. In practice a 1-ton machine has a volumetric efficiency of about 70 per cent. Consequently its actual piston displacement would be 8,491 cubic inches per minute. A 3-inch diameter by 3-inch stroke, single-cylinder, single-acting compressor running at 400 revolutions per minute will give a piston displacement of 8,482 cubic inches, which would perform the work required.

If the back pressure is 15.67 pounds gauge, giving an evaporating temperature of 0° F., and the condensing pressure remains the same (154.5 pounds gauge), the refrigerating effect of 1 pound of ammonia is 472.9 British thermal units, and the weight of ammonia per minute that must be circulated is 0.423 pound per ton capacity.

The volume of the vapor under these conditions is 9.116 cubic feet per pound, and the quantity to be handled is 3.86 cubic feet per minute. The capacity of the machine is therefore reduced 12 per cent by lowering the back pressure 3.93 pounds.

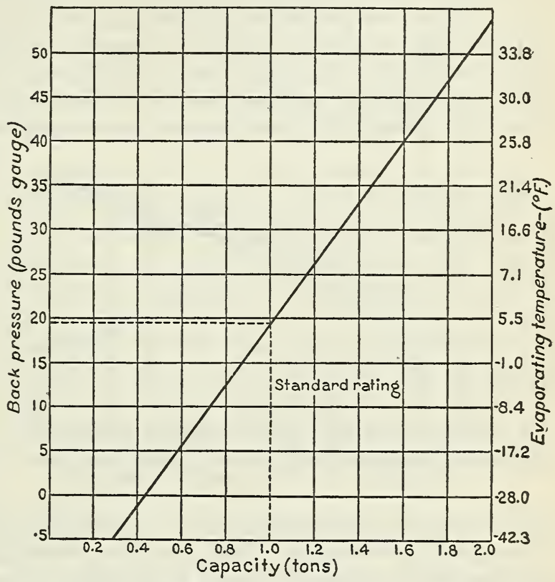

FIGURE 4.—Approximate variation in capacity with variation in back pressure of a 1-ton refrigerating machine

Where direct expansion is employed in milk cooling (p. 19) a back pressure of about 35 pounds gauge, corresponding to an evaporating temperature of 21.4° F., gives sufficient temperature difference between the refrigerant and the milk for satisfactory results. Under these conditions the refrigerating effect of 1 pound of ammonia is 479.3 British thermal units, and the weight of ammonia per minute per ton of refrigeration that must be circulated under the conditions is 0.417 pound. The volume is 5.74 cubic feet per pound, the quantity to be handled is 2.39 cubic feet per minute, and the capacity of the machine is increased above its rated capacity 30.5 per cent.

From the foregoing it is seen that the capacity of a refrigerating machine varies with the back or suction pressure. This relation is shown graphically in Figure 4.

The horsepower required per ton of refrigeration also increases as the difference between the suction and condensing pressure increases. For example, under standard conditions of 5° F. suction temperature and 86° F. discharge temperature:

	B. t. u.
Heat content per pound of ammonia vapor after compression	712.9
Heat content per pound of the vapor before compression	613.3
Heat of compression per pound of ammonia	99.6

Since 1 horsepower is 33,000 foot-pounds per minute and 1 British thermal unit is equivalent to 778 foot-pounds, the heat equivalent of 1 horsepower is $33{,}000 \div 778 = 42.42$ British thermal units per minute. The theoretical horsepower required to compress the 0.422 pound of ammonia per minute necessary to produce 1 ton of refrigeration is $99.6 \times 0.422 \div 42.42 = 0.991$. If the volumetric efficiency of a 1-ton compressor is 70 per cent and the mechanical efficiency is 70 per cent, the brake horsepower required per ton of refrigeration is 2.02.

If the back pressure is raised to 35 pounds gauge, the head or condensing pressure remaining the same:

	B. t. u.
The heat content per pound of the gas after compression	693.0
The heat content per pound of the vapor before compression	618.2
Heat of compression per pound of ammonia	74.8

The weight of ammonia that must be circulated per minute per ton of refrigeration under these conditions is 0.417 pound, and the brake horsepower required is 1.50. Thus by raising the back pressure 15.4 pounds, the condensing pressure remaining the same, the horsepower per ton of refrigeration is reduced $2.02 - 1.50 = 0.52$, or 26 per cent.

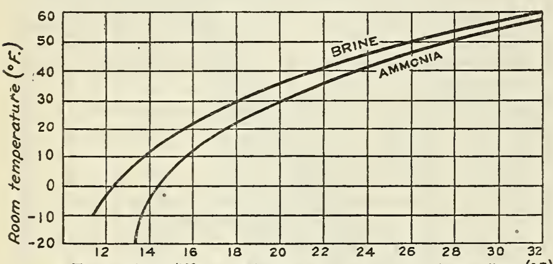

FIGURE 5.—Economical difference in temperature between refrigerator room and cooling medium

A variation in the condensing pressure also affects both the capacity of the condenser and the horsepower required per ton of refrigeration. The condensing pressure should be kept as low as practicable. This can be accomplished by circulating more or cooler water through the condenser. On the other hand, for economy of operation the back pressure should be as high as practicable and yet give the necessary temperature difference between the evaporating liquid and the products being cooled.

In order that the heat in the refrigerating chamber (storage room) may be absorbed readily, the refrigerant should be kept at a temperature considerably lower than that of the room to be cooled. The economical difference varies with the required room temperature. For average storage requirements in dairy plants, temperature differences as shown in Figure 5 will be found practicable.

The rate of heat transfer from the air in the room to the refrigerant inside the coils varies with the rate of air movement over the coils, with the amount of frost or ice on the coils, and with the temperature difference between the air and the refrigerant. For ordinary conditions K, the rate of heat transfer in British thermal units per hour, per square foot of pipe surface, for each degree difference in temperature, will be approximately as shown in Figure 6.

When liquids are cooled by means of direct-expansion piping immersed in the liquid, the rate of heat transfer through the pipe sur-

face from the liquid is much faster than from the air, and the rate of transfer increases rapidly with the velocity of the liquid over the surface. Where the movement of liquid over the pipe surface is very slow, as in the case of natural circulation in a brine tank, the coefficient of heat transfer may be taken as 10 British thermal units per square foot, per hour, for each degree difference in temperature between the refrigerant and the brine.

INSTALLATION

In the installation of compression refrigerating plants the following general directions should be observed:

The compressor, condenser, receiver, and all gages and important valves should be located in a dry, well-ventilated, and well-lighted place where they will be easily accessible for inspection and repairs. The compressor should be mounted on a heavy concrete base to avoid vibration and should be set level to avoid heating of the bearings.

It is particularly important that the receiver and all liquid pipes, valves, and fittings be located in a cool, well-ventilated space. If located in a warm space, such as a boiler and engine room, the heat will vaporize a part of the liquid refrigerant and drive gas back into the condenser to be recondensed; this will result in a greater head pressure and consequent greater power consumption. In a warm location it is necessary either to install a larger condenser or to use more condensing water, or in extreme cases to increase both the size of the condenser and the quantity of water. Furthermore, in a warm space the liquid refrigerant goes to the evaporating coils at a higher temperature, thereby reducing its refrigerating capacity.

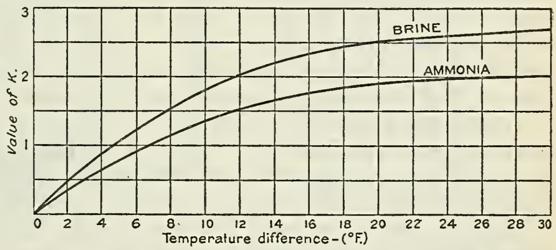

FIGURE 6.—Approximate rate of heat transfer, K, from air to refrigerant, in British thermal units per hour, per square foot, per degree Fahrenheit, with natural circulation of the air

All the main elements of the plant should be conveniently located, with ample clearance for inspection and repairs. The piping should be of adequate size, and unnecessary angles and bends should be avoided. Every foot of piping and all important valves should be easily accessible, especially piping that requires insulation. All coils and branches should be so provided with valves that any coil or branch disabled or not required at any time can be cut out of service.

Great care should be taken to make all pipe joints tight, especially those pipes carrying ammonia in either liquid or gaseous form. Screwed joints should be made absolutely tight by a metal-to-metal contact. It is customary to use a paste of litharge and glycerin for making up joints in ammonia piping. As lubrication, this practice is good, but it should not be employed to cover up defective joints. Clean, perfect dies should be used in cutting the threads. Worn or battered dies cut rough threads that may not make up tight. Where soldered joints are made the threads on the pipe ends and fittings

should be heated and "tinned" with solder before they are made up. Before making the pipe connections, all dirt and scale should be removed from the inside of the pipe and a pipe die run lightly over the threads that have been exposed during shipment, after which they should be carefully washed with gasoline or benzine. The pipe fittings should be cleaned in the same way before connections are made.

When the refrigerating machine is in place and all pipe connections have been properly made, the crank case should be filled with ammonia oil to the level of the crank shaft, or to the line on the frame of the compressor indicating the proper quantity of oil.

LUBRICATION

The internal lubrication of refrigerating machines offers problems entirely different from those of ordinary bearings. Owing to the wide variation in temperature, often ranging from below 0° to above 212° F., ordinary lubricating oils are unsuited. A portion of the oil used for lubricating the internal parts of compressors unavoidably finds its way throughout the entire system and if unsuited to the severe conditions will coat heat-transmitting surfaces with an insulating film or will congeal in the pipes and clog them. Great care should be exercised, therefore, to select internal lubricating oil that has been prepared especially for refrigerating machinery.

Lubricating oils for compressor cylinders have a double duty to perform—to lubricate the wearing surfaces and to prevent leakage of the refrigerating gas past the piston rings. An oil too heavy in body will not be evenly distributed over the wearing surfaces and will cause excessive fluid friction due to its high viscosity. On the other hand, an oil too thin or light in body will not maintain the required thickness of film to afford the necessary lubrication and to seal effectively against leakage of gas and may vaporize so freely as to be carried away by the hot compressed gas.

Reliable manufacturers of refrigerating machinery have studied the problem of lubrication and are in a position to furnish or recommend a satisfactory oil. Their recommendations should be followed implicitly. An inferior oil will, in a very short time, cause operating losses greatly exceeding the difference in cost between a poor and a high-grade oil.

THE ABSORPTION SYSTEM OF REFRIGERATION

The absorption system is based upon the alternate absorption and expulsion of ammonia gas by water. Water at low pressures and temperatures will absorb hundreds of times its own volume of ammonia gas and at high temperatures and pressures will give up this gas. The principles on which this system of refrigeration operates is illustrated in Figure 7.

The essential parts of an absorption refrigerating system are an evaporator (in the refrigerator, fig. 7), an absorber, an ammonia pump, a generator, and a condenser. The absorber is filled with aqua ammonia,[1] which is circulated through the absorber and the generator by the pump.

[1] Aqua ammonia is a solution of ammonia in water; pure ammonia, either gas or liquid, is anhydrous ammonia.

In the evaporator, the liquid ammonia vaporizes, the heat required for this process being absorbed from the substance surrounding the evaporator coils. The necessary low pressure in the evaporator results from the rapid absorption of the anhydrous ammonia gas by the weak aqua ammonia in the absorber. This absorption of the gas by the weak solution generates heat, which is carried off by the cooling water circulating through coils in the absorber. The ammonia solution, made stronger by the refrigerant absorbed, is pumped into the generator. There it is heated, usually by low-pressure steam. Under the influence of the higher temperature and the consequent high pressure the ammonia gas is driven out. The weakened solution is then returned to the absorber. In the heat exchanger, the weak

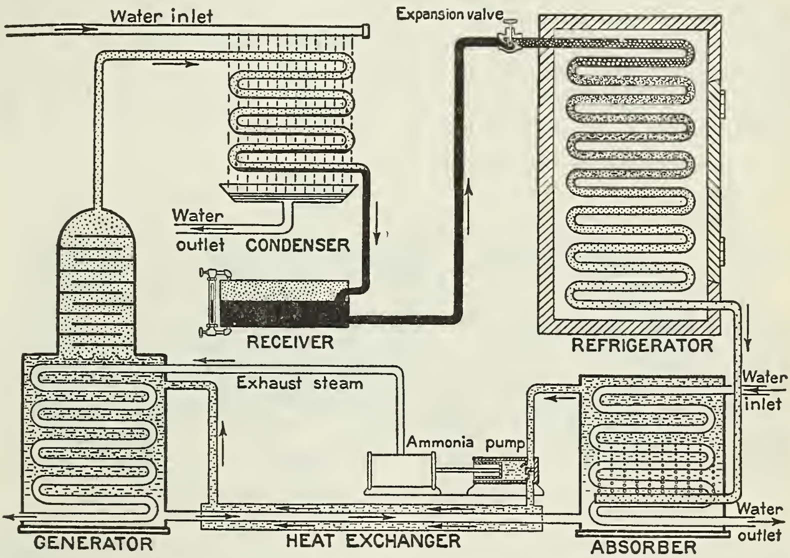

FIGURE 7.—Essential members of an absorption refrigerating system

solution coming from the generator through the inner space gives up part of its heat to the stronger solution flowing to the generator through the outer space, and heat is conserved. The ammonia gas released in the generator then passes into the condenser, where its heat is taken out by the cooling water and it returns to liquid form. It flows next into the receiver, and thence through an expansion valve (p. 3) into the evaporator to absorb more heat from the refrigerator.

OPERATING ELEMENTS

A general arrangement of a vapor-absorption system with all the necessary elements properly connected, is illustrated in Figure 8. These elements are as follows: Evaporator (in brine cooler) absorber, ammonia pump, heat exchanger, generator, analyzer, rectifier, condenser, liquid-ammonia receiver, expansion valve, weak-liquor cooler, oil separator, steam traps, gages, and the necessary piping and valves.

The evaporating coils may be located directly in the cold-storage room, in a brine cooler, or in an ice tank, just as with a compression system of refrigeration. Evaporation of the liquid ammonia is caused by the low pressure maintained in these coils. In the compression system the low pressure obviously is produced by the suction of the compressor. In the absorption system, however, it is produced and maintained by the rapid absorption of the ammonia gas by the cool, weak ammonia liquor in the absorber.

The function of the absorber is to absorb the ammonia gas formed in the evaporating coils. In order for absorption to take place rapidly, it is necessary that the liquor in the absorber be kept cool, that the gas be thoroughly mixed with liquor, and that the strength of the solution be kept relatively low. The heat liberated in the absorption of gas by the liquor, along with a part of the sensible heat of the liquid, is constantly removed by the circulation of cool water through the absorber. Mixing of the gas with the liquor is accomplished by allowing the gas to enter the absorber near the bottom through perforated pipes. Thus distributed, it rises in the

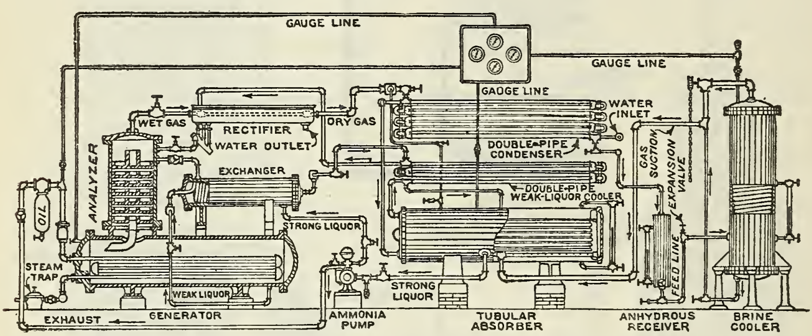

Figure 8.—General arrangement of an absorption refrigerating system

mass of cool, weak solution and is readily absorbed, increasing the strength of the solution. To keep the operation of the absorber continuous, the now concentrated solution is gradually pumped out and replaced with the weak liquor from the generator.

The ammonia pump transfers the strong ammonia liquor from the absorber to the generator.

The duty of the generator is to distill off the ammonia gas from the solution of aqua ammonia. This serves the double purpose of salvaging the refrigerant for use again, after condensation, in the evaporator and of weakening the ammonia liquor for reuse in the absorber. Heat for this distillation is usually supplied by pipe coils containing steam at pressures varying from 3 to 25 pounds. Generators for using exhaust steam are designed for steam pressures of about 3 to 5 pounds. The ammonia vapor from the boiling solution of ammonia and water is forced through the analyzer and rectifier into the condenser.

The analyzer, connected to the top of the generator, consists of a number of plates or baffles arranged to break up the strong liquor (aqua ammonia) coming from the absorber and to unite it with the hot vapors rising from the generator. Those vapors contain con-

siderable steam or water vapor, and the cool liquor from the absorber condenses the greater part of this and the resulting liquid falls back into the generator. On the other hand, a part of the ammonia in the liquor coming from the absorber is vaporized by contact with the hot vapors from the generator and passes directly to the condenser. Consequently the analyzer embodies, to a certain extent, the functions of both heat exchanger and dehydrator or rectifier.

The purpose of the rectifier or dehydrator is to remove any water vapor and entrained water being carried with the ammonia gas. It is very important that only pure ammonia gas enter the condenser. If water vapor is allowed to enter, it will be condensed along with the ammonia gas and will pass into the evaporator where it will clog the coils unless pumped out frequently. The rectifier usually consists of a water-cooled pipe coil through which the ammonia gas passes on its way to the condenser. Any steam in the ammonia gas is condensed and with the entrained water is trapped back into the analyzer and from there falls into the generator. Some ammonia gas also will be condensed, as it is impracticable to so adjust the temperature in the rectifier as to condense only the water vapor, but by keeping the temperature in the rectifier slightly above that in the condenser the greater part of the water vapor and only a small portion of the ammonia will be condensed.

The function of the condenser in the absorption system is identical with that in the compression system, namely, to condense the gaseous refrigerant into a liquid.

The receiver in both the absorption and the compression system is simply a reservoir to receive and store the liquid refrigerant.

The function and the importance of the expansion valve is the same in both systems of refrigeration and has already been discussed (p. 3).

The heat exchanger is an efficiency unit. Its function is to economize heat by transferring it from the hot to the cold liquid. The exchanger economizes not only heat in the generator but also cooling water in the weak-liquor cooler and in the absorber. Since the operation of this refrigerating system depends upon a high temperature in the generator and a low temperature in the absorber, it follows that if a part of the heat in the hot, weak liquor passing from the generator can be transferred to the cold, strong liquor from the absorber, thus cooling the former and warming the latter, a material saving of heat can be effected. The lower the temperature of the weak liquor on entering the absorber, the greater affinity it will have for the ammonia gas.

The weak liquor-cooler, like the heat exchanger, is a heat economizer. It usually consists of a countercurrent form of cooler, through which the weak ammonia liquor passes in a direction opposite to that of the cooling water. The weak liquor, after passing through to the cooler, sprays into the top of the absorber and there because of its lower temperature absorbs the ammonia gas from the evaporating coils.

ADVANTAGES OF THE ABSORPTION REFRIGERATING SYSTEM

The only power required by the absorption system of refrigeration is that necessary to circulate the various liquids, which is incon-

siderable in comparison with the power required by the compression system. The amount of cooling water required, however, exceeds that used by a compression plant of the same capacity, because water is required in the condenser, the absorber, the weak-liquor cooler, and the rectifier, whereas in a compression system water is required only in the condenser and in the water jackets of the compressor cylinders. Sometimes the cooling water is used successively in different parts of an absorption plant, thereby economizing in the quantity used.

The absorption system of refrigeration is employed when low temperatures are required, because the single-stage ammonia compression system is not economical for producing temperatures much below 0° F. It can be used to advantage also where a large amount of exhaust steam would otherwise be going to waste. Often the exhaust from the pumps of a dairy plant furnishes sufficient heat. Employed in conjunction with a steam-driven compression plant, the exhaust from the compressor engine may be used in the generator of the absorption plant. Such an arrangement is especially economical where both high and low temperatures are required. In large ice-cream plants the combination of the two systems is especially applicable, as comparatively high temperatures are used in storing materials, in aging the mix, and in the initial freezing, whereas low temperatures are required for hardening the cream.

INSTALLATION

It is not practicable to give here detailed instructions covering installing, charging, and operating an absorption refrigerating system, as local conditions and the use to which the plant is to be put, determine largely the best arrangement and method of operation. The following points, however, may be noted.

There are no moving parts in the absorption refrigerating system except the ammonia pump; hence the foundations need be only strong enough to support the dead weight of the apparatus. The system should be located in a clean, dry, well-ventilated, and well-lighted place. Each part should be set perfectly level. There should be ample space between the parts for inspection and repairs. The piping connecting the different parts should be run as direct as possible, avoiding all unnecessary bends and angles. Valves should be located where they can be easily reached by the attendant, especially those valves that require frequent manipulation.

The discussion relative to the preparation and installation of pipes for the compression system of refrigeration (pp. 2 to 8) applies also to the absorption system.

INSULATION

The purpose of insulation is to reduce the quantity of heat passing to or from a particular body or space. The problem of insulation is, therefore, to surround that body or space with a material or construction or a combination of the two, through which heat will pass slowly. There is no material that will entirely prevent the passage of heat, but there are some that offer very high resistance and are, therefore, termed nonconductors or insulators. The better the ma-

terial and the more of it used, the less the amount of heat that will pass through it in a given time and hence, for a refrigerating chamber, the less the refrigeration required for removing that heat. The amount of insulation to be used in any case, however, should not exceed that for which interest on the money invested, repairs, and depreciation will equal the saving in operating expense.

INSULATING MATERIALS

The best heat insulators appear to be those that contain the most entrapped air confined in the smallest spaces. The materials most commonly used for insulating purposes are the different kinds of cork products, mineral wool, rock wool, hair felt, vegetable fiber, mill shavings, etc., used in combination with wood, cement, masonry, and air spaces. Large air spaces do not provide very effective insulation, because the moving air within the air spaces acts as a heat carrier from the warmer to the cooler surface. Dead air is a good nonconductor of heat, however, and convection currents in large spaces may be prevented by filling the spaces with some porous substance such as granulated cork, sawdust, or mill shavings. Yet if the porous insulating material is packed too closely, there may be considerable transfer of heat through the material by conduction.

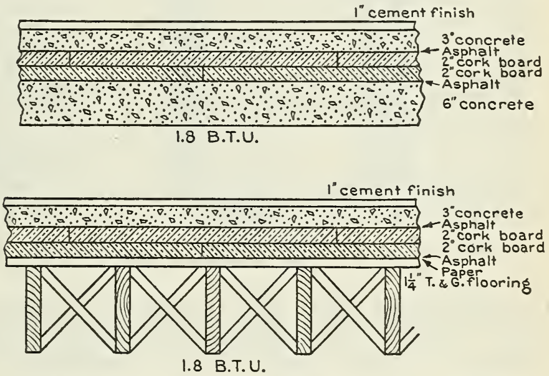

FIGURE 9.—Typical floor construction for cold-storage rooms, and the coefficient of heat transfer in British thermal units

Sawdust and mill shavings are not to be considered among the best insulating materials, but they are cheap and if kept dry serve fairly well. They readily absorb moisture from the air, and where they are used great care should be taken in construction of the walls in order to keep out moisture. Planing-mill shavings generally are better than sawdust. They are elastic, do not settle rapidly, will not absorb moisture so readily as sawdust, and—of more importance—can usually be had in a dry condition. They should be odorless and free from dirt, bark, and chips. They should be well packed into place to prevent future settling, about 9 pounds per cubic foot being considered the proper density. Sawdust is always more or less damp, and the dampness not only reduces its insulating value but also favors the growth of molds and bacteria in the sawdust and in the wall materials. The rotting causes the sawdust to settle and leave open spaces which further weaken the insulation. When sawdust is used, it should be thoroughly dried out before being placed in the walls, and means should be taken to keep out air and moisture.

In selecting a type of insulation, the following points should be carefully considered: Efficiency as a heat insulator; uniformity and

permanence of insulating value; structural strength; effect of moisture; resistance to fire; space occupied; cost of materials; and cost of installation.

When placing insulation in the walls, floors, and ceilings of cold-storage rooms, it is of utmost importance that the workmanship

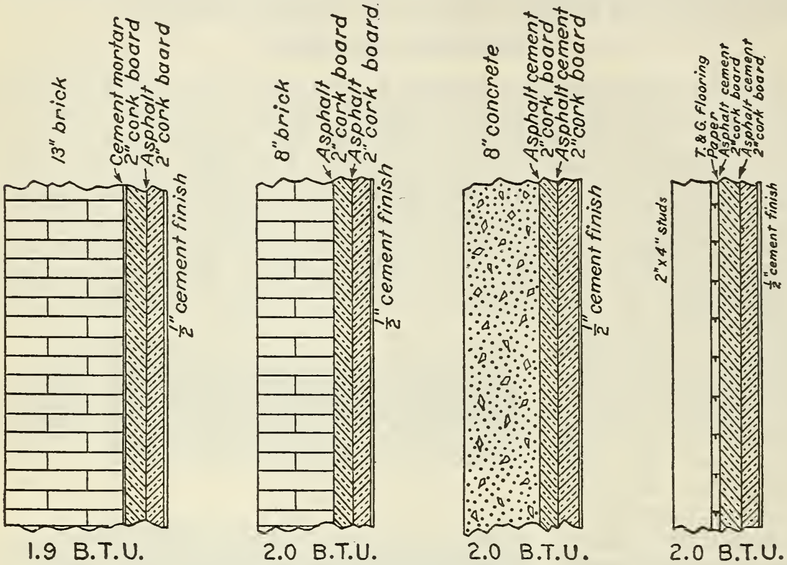

FIGURE 10.—Typical wall construction for cold-storage rooms, and the coefficient of heat transfer in British thermal units

be of the very best. The insulation should be continuous; that is, there should be no breaks in continuity where walls meet floor, ceiling, or other walls. When installing board insulation, each course should be set before the next course is applied. In all cases the blocks of insulation should fit tightly together. No cement or asphalt should be used in the joints, but only on the backs of the blocks. The blocks should be further secured in place by wooden skewers or galvanized-wire nails. The interior surface of the room should be finished with a hydraulic-cement plaster, asphaltic compound, or other material that will permit of thorough washing. Figures 9 to 12 show a number of practical constructions, together with their insulating values.

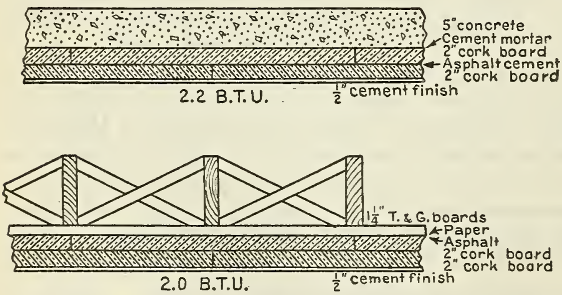

FIGURE 11.—Typical ceiling construction for cold-storage rooms, and the coefficient of heat transfer in British thermal units

COEFFICIENT OF HEAT TRANSFER

The theoretical consideration of the flow of heat through insulating material is complex, but for practical work simple formulas are used which give results sufficiently accurate.

The number of heat units (British thermal units) that will pass through 1 square foot of any material 1 inch thick, in 24 hours, for each degree difference in temperature between its two sides is the thermal conductivity of that material. It is usually designated by the letter C. Experimental determinations of C are given in Table 1. The coefficient of heat transfer of a material or construction of any thickness is designated by the letter K. If T is the thickness in inches of the material, $K=\frac{C}{T}$, and represents the quantity of heat that will pass through 1 square foot of the material in 24 hours for each degree of difference in temperature between the two sides. Thus the total heat that will pass through the walls, ceiling, and floor into a room in 24 hours would be computed as—

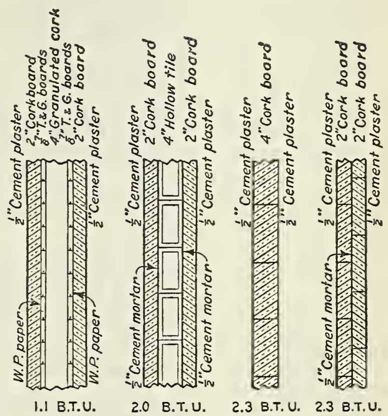

FIGURE 12.—Typical partition construction for cold-storage rooms, and the coefficient of heat transfer in British thermal units

$$Q=A\times K\ (t_1-t_2).$$

where

Q=total quantity of heat in British thermal units per 24 hours.
A=area of the surface of the room in square feet.
K=coefficient of heat transfer.
t_1=average outside temperature.
t_2=average inside temperature.

TABLE 1.—*Thermal conductivity of various insulating and building materials*

(Adapted from the United States Bureau of Standards tables)

Material	Remarks	Thermal conductivity (C [1])	Density (D) per cubic foot
			Pounds
Air	If no heat is transferred by radiation or convection	4.2	0.08
Calorox	Fluffy mineral powder	5.3	4.0
Kapok	Hollow vegetable fibers loosely packed	5.7	.88
Pure wool		5.9	6.9
Do		5.9	6.3
Hair felt	Fibers perpendicular to heat flow	5.9	17
Pure wool		6.3	5.0
Slag wool	Loosely packed	6.3	12
Keystone hair	Hair felt and other fibers confined with building paper	6.5	19
Mineral wool	Loosely packed	6.5	12
Cork board	No artificial binder, low density	6.5	6.9
Mineral wool	Fibers perpendicular to heat flow	6.9	18
Cotton wool	Medium packed	7.0	5.0
Pure wool	Very loose packing, probably air circulation through material.	7.0	2.5

TABLE 1.—*Thermal conductivity of various insulating and building materials*—Continued

Material	Remarks	Thermal conductivity (C[1])	Density (D) per cubic foot
			Pounds
Insulite	Pressed wood pulp	7.1	12
Mineral wool	Firmly packed	7.1	21
Linofelt	Vegetable fiber confined with paper. Flexible and soft	7.2	11.3
Ground cork	Less than 1/16 inch	7.1	9.4
Cork board	No artificial binder	7.3	9.9
Do	do	7.4	11.3
Sil-O-Cel	Pulverized	7.4	10.6
Regranulated cork	About 3/16 inch	7.5	8.1
Balsa wood	Very light wood, across grain	7.5	7.1
Do	Same sample with 13 per cent water-proofing compounds	8.3	8.0
Cottonseed hull fiber	Loosely packed	7.5	4.4
Cabots quilt	Eel grass inclosed in burlap	7.7	16
Flaxlinum	Felted vegetable fibers	7.9	11
Fibrofelt	do	7.9	11
Rock cork	Mineral wool and binder	7.9	16
Ceiba wood	Across grain, untreated	7.9	7.1
Balsa wood	do	8.3	7.4
Burrash	Confined with cloth	8.1	8.8
Cork board	With bituminous binder	8.4	16
Wood felt	Flexible paper stock	8.7	21
Lithboard	Mineral wool, vegetable fibers, and binder	9.1	1258
Balsa wood	Medium-weight wood	9.2	8..
Sawdust	Various	9.7	12
Planer shavings	do	10	8.8
Wall board	Stiff pasteboard	12	43
Air cell, ½ inch	Corrugated asbestos paper inclosing air spaces	11	8.8
Air cell, 1 inch	do	12	8.8
Asbestos paper	Built of thin layers	12	31
Zenitherm	Infusorial earth and asbestos	12	16
Magnesia (85 per cent)	Magnesia and asbestos	12	19
Insulex	Asbestos and plaster blocks, very porous	13.5	18
Sil-O-Cel	Infusorial earth, natural blocks	14	28
Do	do	15	31
Balsa wood	Heavy	14	20
Fire felt sheet	Asbestos sheet coated with cement	14	26
Fire felt roll	Flexible asbestos sheet	15	43
Cypress	Across grain	16	29
Fuller's earth		17	33
Asphalt roofing	Felt saturated with asphalt	17	55
White pine	Across grain	19	32
Asbestos mill board		20	61
Mahogany	Across grain	22	34
Virginia pine	do	23	34
Oak	do	24	38
Maple	do	27	44
Sole leather		26	62
Rubber	Soft vulcanized	29	69
Textan	Rubber composition	28	81
White celluloid		35	88
Paraffin	Parawax, melting point 52° C	38	56
Gypsum plaster		56	46
Asbestos wood	Asbestos and cement	65	123

[1] In British thermal units per day (24 hours) per square foot per degree Fahrenheit per inch thickness.

In practice, walls, floors, and ceilings are built up of different materials, and the coefficient of heat transfer of the built-up section is the reciprocal of the conductivities of the different materials.

That is

$$K=1\Big/\left(\frac{T_1}{C_1}+\frac{T_2}{C_2}+\frac{T_3}{C_3}+----\right)$$

where T_1, T_2, etc., equals the thicknesses of the separate elements in inches and C_1, C_2, etc., equals the respective conductivities.

The values of C in Table 1 were determined from laboratory tests. In practice, edges and corners of the insulating materials may be broken off, the joints are not always tight, and other defects in work-

manship occur. Consequently the heat leakage into the room probably would exceed the computation by 10 to 20 per cent.

Thicknesses of cork-board insulation considered economical for refrigerating milk and milk products are shown in Figure 13.

COLD-STORAGE DOORS AND WINDOWS

Doors are the source of considerable loss of refrigeration in cold storage. They should be well insulated, but it is much more important that they operate quickly and close tightly. A poor-fitting door that permits the air to leak into the room causes rapid temperature changes and a great increase in the amount of refrigeration required. Consequently great care should be taken in fitting the doors and in closing them quickly. Usually it is economy to buy a good commercial door, as it will fit better and will not be so likely to warp as one built by a local carpenter. Heavy doors and doors that warp and bind badly are left open longer by workmen entering cold-storage rooms than are light and easily operated doors.

Equal care should be used in the construction and fitting of windows. For an inside temperature of 35° F. they should be constructed of at least three plates of glass, separated by ¼-inch air spaces. The glass plates should be set in felt and the spaces made air-tight.

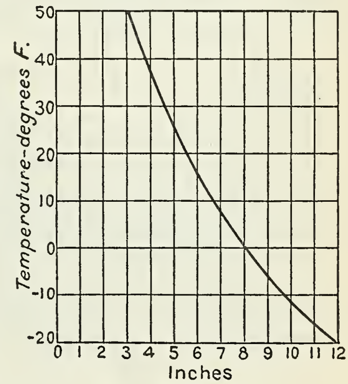

FIGURE 13.—Economical thickness of cork-board insulation for different storage-room temperatures

WATERPROOFING

Walls and floors that are likely to be damp should be carefully waterproofed before insulation is applied, because moisture penetrating the walls and insulation will increase the heat conductivity and cause rapid deterioration of the insulation. Where the insulation is erected against the walls in a bed of cement plaster the plaster is likely to become damp and result in weakening the bond between it and the insulation. Dampness is most likely to occur in floors; consequently the base on which the insulation for a floor is to rest should be flooded with hot asphalt to a depth of at least one-eighth inch. The insulation then should be laid down in this hot asphalt and the top of it flooded with an equal thickness of hot asphalt. Brick and concrete walls may be waterproofed by applying hot asphalt. It should be applied preferably to the outer side of the walls, thus preventing moisture from penetrating the wall and increasing its heat conductivity.

INSULATION OF PIPES AND TANKS

The insulation of pipes, valves, and fittings carrying cold liquids or gases is equally as important as insulation of the storage room. Insulation properly applied and maintained not only saves refrigeration but also protects the metal surfaces from rust and corrosion.

Any metal surface in contact with the air on one side and a low-temperature medium on the other will be either wet or covered with frost, depending upon the temperatures of the two sides. Such a condition results in rapid corrosion.

Exposed bare pipe carrying low-temperature liquids or gases will, under average conditions, absorb about 43 British thermal units per 24 hours, or 1.8 British thermal unit per hour, per square foot of surface, for each degree difference in temperature between the cold medium inside the pipe and the air surrounding it.

Insulation on pipes, valves, and fittings must be carefully fitted. If cracks or voids allow air to come in contact with the cold pipe surface, moisture will freeze under the insulation and destroy it in a very short time. Before the insulation is placed, the pipes should be thoroughly cleaned and painted with a heavy coat of waterproof asphaltic paint and then allowed to become thoroughly dry. Molded cork covering comes in halves, 3 feet long. The first half applied should be cut off in the middle to give a joint halfway around the pipe every 18 inches. The longitudinal joints should always be placed at the top and bottom of the pipe. The covering should fit snugly, broken corners or edges should be built up, and the seams and joints should be completely filled with brine putty or seam filler. As the covering is installed it should be rigidly bound in place with heavy copper-plated wire, at least 6 wires being used on each 3 feet of pipe and from 4 to 6 wires on each fitting. After installation the covering should be given a heavy coat of waterproof asphalt paint. The insulation should be inspected frequently, and any broken binding wires, open seams, or other defects should be repaired immediately.

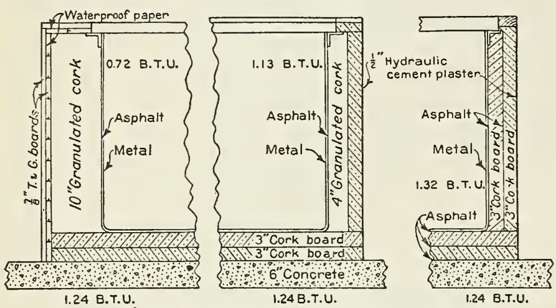

FIGURE 14.—Typical brine-tank insulations

Typical constructions for insulating brine tanks are illustrated in Figure 14. Special attention should be given to the insulation of the bottom when the tank is placed directly on the ground, otherwise serious damage may result from freezing and upheaving of the ground. If a low temperature is maintained constantly in the tank for long periods, there will be a tendency for the temperature of the outer side of the insulation to approach that of the inner side. Therefore sufficient insulation must be used to insure that heat will pass through the insulation more slowly than through the ground. The equivalent of at least 8 inches of cork board should be used when a temperature of 0° is to be maintained in the tank for long periods.

METHODS OF UTILIZING REFRIGERATION

There are a number of methods employed for utilizing refrigeration, each one offering advantages under certain conditions and requirements.

DIRECT EXPANSION

The direct-expansion method consists in evaporating the liquid refrigerant in pipe coils located in the room or space to be cooled. It is the simplest and cheapest method to install and is the most economical to operate where the plant is to run practically continuously. It has the disadvantage, however, of not being able to store up any considerable amount of refrigeration, thus requiring practically continuous operation. In milk cooling, usually a large amount of refrigeration is required for only a short time, and in the past the general practice has been to store up refrigeration to aid in handling this heavy load by cooling a large volume of brine to a low temperature, thus utilizing a somewhat smaller refrigerating machine. The present tendency, however, is to apply the evaporating refrigerant directly in the cooling equipment, and to provide ample machine capacity to perform the cooling in the time allotted. In many instances the greater efficiency of the direct method overbalances the additional cost of the larger refrigerating equipment. Direct expansion is being successfully applied to the cooling of dairy products at all stages of handling and manufacturing.

DIRECT-EXPANSION MILK COOLERS

The successful application of direct expansion to milk coolers is not a simple matter. An increase in either quantity or temperature of the milk flowing over or through a milk cooler puts a greatly increased load on the refrigerating equipment almost instantaneously, and means must be provided for handling this burden. There must be ample space for liberating the vapor resulting from the boiling refrigerant and for removal of the vapor from the coils, otherwise slugs of the liquid will be carried along with the vapor to the refrigerating machine.

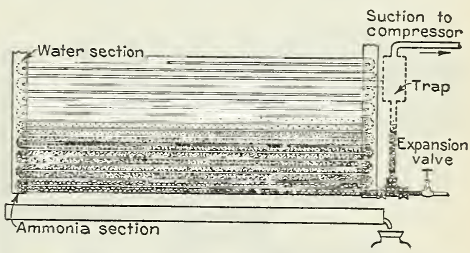

FIGURE 15.—One of the first direct-expansion milk coolers

One of the first arrangements employed for cooling milk by the direct expansion of ammonia is shown in Figure 15. The liquid ammonia entered the cooler coils at the bottom, through a hand-operated expansion valve. The violent boiling of the ammonia in the bottom coils as the warm milk passed over them caused slugs of liquid to be carried over to the compressor. This effect was accentuated by a varying flow and temperature of the milk. A trap installed to collect these liquid slugs and to prevent their passing to the compressor did not prove satisfactory in practice, as it was impossible to regulate the hand valve in conformity with the variation in flow and temperature of the milk. To prevent the ammonia from boiling over, it was necessary to so reduce the quantity fed into the lower coils that a number of the upper coils were simply filled with vapor and hence were of little value in cooling the milk.

A number of arrangements have been designed for relieving the cooler of these conditions, one of which is shown in Figure 16. The ammonia receiver is located below the cooler, and the liquid ammonia is maintained at a constant level by means of a float valve. A circulating pump transfers liquid from the receiver to the upper coil of the refrigerated section of the cooler, whence it flows downward through the coils to the receiver, the excess liquid draining back into the receiver. The pump circulates considerably more liquid than is required for cooling, even with increases of hot milk over the cooler, hence there is always some liquid trickling back into the receiver. The receiver is of ample capacity to hold the liquid and also provides space for flash gas from the liquid feed as well as for the gas from the cooler coils passing to the compressor. A regulating valve in the suction line to the compressor maintains a constant back pressure of about 35 pounds per square inch on the ammonia system in the cooler. With this arrangement all the cooler tubes contain liquid and hence are all effective in cooling the milk.

By means of the by-pass valve the refrigerant can be diverted back to the receiver without passing through the cooler coils and at the same time any liquid ammonia that may be contained in the coils is drained to the receiver, thus emptying the coils quickly. Cleaning and sterilizing the cooler can be commenced at once with this arrangement.

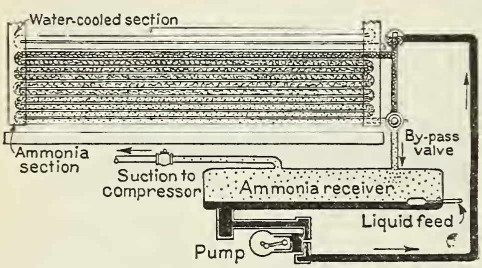

FIGURE 16.—One of the latest arrangements for direct-expansion milk coolers

Direct expansion as applied to ice-cream freezers has two advantages over the brine type: (1) The freezing operation can be started at once with the starting of the compressor and without waiting for brine to be cooled; and (2) for quick freezing, temperatures as low as −15° F. are readily obtained with direct expansion but are impracticable with brine. The temperature in the freezer can be accurately controlled. With a complete direct-expansion system of refrigeration the advantages and economies obtained are: (1) The capacity of the machine is increased, because a higher back pressure can be employed; (2) the horsepower required per ton of refrigeration is less, because less power is required in compressing the gas from the pressure existing in the evaporating coils to that existing in the condensing coils; and (3) the brine pumps, brine coolers, and brine-storage tank are eliminated, resulting in materially reducing the cost of equipment, the space occupied, and the power required.

BRINE CIRCULATION

The brine-circulation method of refrigeration is illustrated in Figure 17. The pipe coils in which the refrigerant is evaporated are located in an insulated tank, or in a specially designed brine cooler, containing brine of a density that will insure a low freezing temperature. The cold brine is pumped through pipe coils located in the cold room or other space to be cooled. The brine absorbs

heat from the room and is returned to the brine tank or brine cooler where it is again cooled and recirculated. Consequently, there is a double transfer of heat from the air in the room to the brine and from the brine to the evaporating coils.

The advantages of the brine-circulation method of refrigeration are: (1) A considerable amount of refrigeration can be stored up in the brine for quick action when needed, and low temperatures can be maintained for some time after the refrigerating machine is stopped; (2) the possibility of the volatile refrigerant escaping in the cold room is avoided; and (3) usually the quantity of volatile refrigerant required in the brine-circulating system is much less than in the same size direct-expansion plant.

This method has the disadvantage of being more expensive to install and to operate than a direct-expansion system. It requires, in addition to the members of the direct-expansion method, a brine pump, a brine tank, and brine coils, and often a brine cooler. Additional power is required to operate the brine-circulation system, (1)

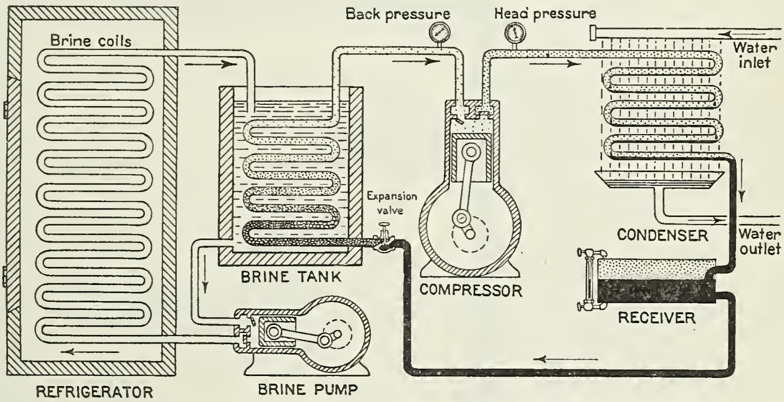

FIGURE 17.—Elementary diagram of brine-circulation method

to pump the brine from the tank through the coils and back to the tank, (2) to provide additional refrigeration to compensate for the heat produced mechanically by circulating the brine and the heat absorbed through the walls of the brine tank and the exposed brine piping, and (3) to operate the plant at a back pressure that will produce a temperature in the evaporating coils low enough to effect the double transfer of heat between the air in the cold room and the refrigerant.

More pipe surface is required for direct expansion than for brine circulation, even though in the former case a greater mean-temperature difference is maintained between the air in the room and the refrigerant inside the pipe. This is because the coefficient of heat transfer is greater with brine than with direct expansion. The direct-expansion pipes are partly filled with gas or vapor, which is not so effective as the boiling liquid, whereas the brine pipes are completely filled and hence all parts are equally effective.

The brine-circulation system requires about one-third more refrigeration in the expansion coils than does the direct-expansion system.

This is to remove heat absorbed through the brine tank and brine pipe insulation and the heat equivalent of the mechanical work of circulating the brine through the coils.

BRINE COOLERS

There are commercial brine coolers that accomplish a more rapid transfer of heat from the circulating brine to the evaporating refrigerant than is obtained with a brine tank containing the direct-expansion coils, because of the better arrangement of the heat-transfer surfaces and the higher rate of brine flow. They are not intended to contain large volumes of brine, so usually a brine-storage tank is installed in connection with them. Brine coolers must be operated with care, or the brine passing through them is likely to freeze and burst the tubes or shell.

Three types of brine coolers are the shell and tube, the shell and coil, and the double-pipe countercurrent. The coefficient of heat transfer in the shell and tube coolers is from 90 to 100 British thermal units per square foot per hour for each degree difference between the brine and refrigerant. The shell and coil cooler, used only for relatively small refrigerating systems, has a coefficient of heat transfer of about 70, and the heat-transfer surface is about 17 square feet per ton of refrigeration. In the double-pipe countercurrent cooler the coefficient of heat transfer is from 100 to 150, depending upon the velocity of the brine, and the surface required per ton of refrigeration is 8 to 12 square feet.

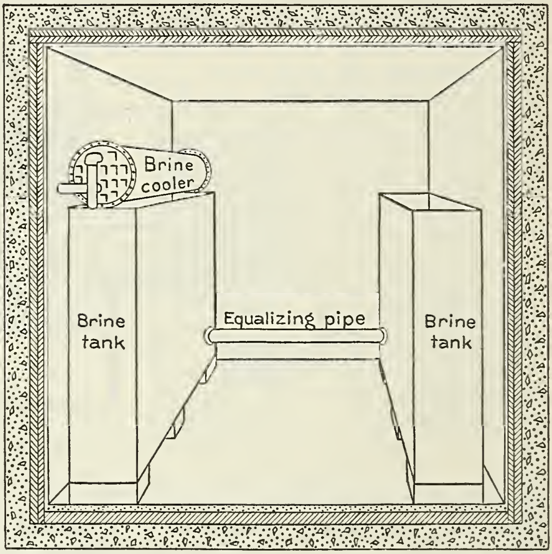

FIGURE 18.—Brine-storage tanks and brine cooler installed in refrigerating room

Usually the cooler is connected into the brine circuit between the brine-storage tank and the room coils, with the circulating pump between the storage tank and cooler. Thus the brine is drawn from the storage tank or reservoir and forced through the cooler, through the room coils, and back to the storage tank. This arrangement sends the coldest brine directly to the refrigerating room.

BRINE STORAGE

The brine-storage method is a modification of the brine-circulation method. Its object is the storage of cold brine either in the cold room or in a specially designed and insulated tank located out-

side the cold room. When the brine tanks are located inside the cold room, they are not insulated and act to maintain a low temperature in the room. This arrangement is shown in Figure 18. When located outside, the brine must of course be pumped through cooling coils inside the room.

CONGEALING TANK

The congealing-tank method is similar to the brine-storage method just described, but uses a weak brine and freezes a part of the water in it on the direct-expansion coils. It utilizes the latent heat of the ice to store a large amount of refrigeration in a small space. Much less brine is required than for brine storage of the same capacity.

In a congealing-tank system, ample space must be left between the expansion coils and the sides of the brine tank, and in operating the system care must be taken not to allow the brine to freeze solid. If the brine freezes solid, melting during the subsequent hold-over period may not open sufficient spaces between the ice and the sides of the tank to permit ready circulation of the brine when the machine is started again. The smaller spaces at the sides will freeze before the larger space in the bottom of the tank; then when the liquid trapped in the bottom freezes, the expansive force may rupture the tank. To lessen the danger of such rupture, sometimes the sides of the tanks are made of sheet steel with vertical corrugations.

In practice, the congealing tank commonly is only one-half to one-third the size that would be required for a brine-storage tank. The smaller space and the less weight to be supported measurably simplify construction for the system.

The brine employed in the congealing-tank system is usually calcium chloride, because it does not crystallize out of solution as much as does sodium chloride, and the small calcium chloride crystals are dissolved more readily by the water from the melting ice. The melting point of the brine ice is determined by the strength of the solution, which in turn is established by the temperature desired in the storage room.

COLD-STORAGE ROOMS

When the goods in storage are once cooled to the desired temperature it is only necessary, in order to maintain a low temperature, to remove the heat that enters through the walls, floor, and ceiling. The heat entering the room is in direct proportion to the surface area, consequently the smallest ratio of surface area to cubical content is desirable. A cube has less surface area for a given volume than any other practical shape. The cubical form is limited, however, to dimensions about 10 or 12 feet because a height much less than 10 feet is insufficient for overhead bunkers and free circulation of air, while other dimensions much greater than 12 feet make construction more expensive. A compromise therefore is necessary for both larger and smaller rooms, but long and narrow rooms are to be avoided where possible.

The cold-storage rooms should be located in the cooler part of the building, where practicable, and protected from the direct rays of the sun. When adjacent to boiler, engine, or processing rooms, where temperatures are likely to be high, more insulation should be

provided in order to compensate for the higher surrounding temperature, or more refrigeration will be required to maintain the required temperature. A difference of only a few degrees in the surrounding temperature will make a material difference in the cost of maintaining the room temperature.

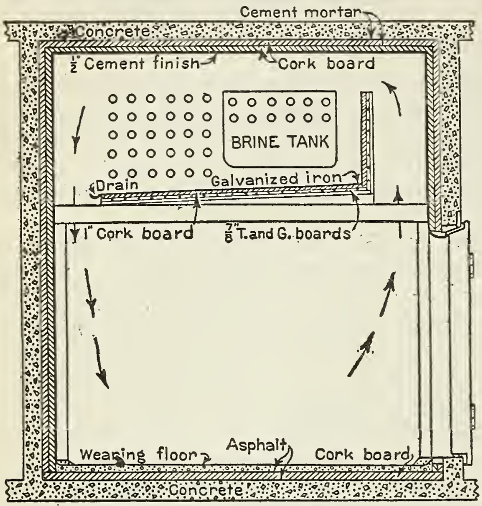

FIGURE 19.—Typical cold-storage room with single overhead bunker and open hold-over brine tank

The interior arrangement of the cold room as regards location of cooling coils, warm and cold air ducts, and baffles is very important. To produce and maintain a positive guided circulation of air there must be sufficient height and there must be no throttling of the air through restricted openings. The movement of air in a cold-storage room, except forced circulation by the use of a fan, is caused by the difference in weight of cold air and warmer air. The relative weights of the different portions of the air depend upon the differences in temperature, and since the temperature differences are only a few degrees the circulation is relatively slow. The heights of the air columns should be as great as practicable, and care should be taken to keep the warm-air column from being cooled before it reaches the refrigerating coils and to keep the cold-air column as cold as possible until it nears the floor of the room.

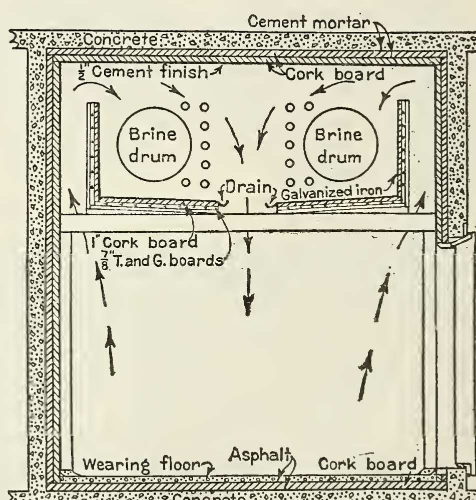

FIGURE 20.—Typical cold-storage room with double overhead bunker and brine drums

The uptake or warm-air duct should be located on the side of the room that is likely to be the warmest. Usually this will be the side containing the door to the room, for the door is usually a weak point in the insulation, and when it is opened there is generally some leakage of warm air into the room and of cold air out. Location of the warm-air duct on the side of the room containing the door will utilize this change of air for increasing the rate of circulation.

Great care should be taken to prevent cross currents of air in the cold room, for when such currents come in contact the rate of circulation is retarded and condensation takes place. The rising warm air has absorbed moisture from the goods in storage until practically saturated, and when cooled by coming in contact with the colder air its temperature is reduced below the dew point and moisture results. With properly insulated bunkers and well-proportioned ducts the circulation will be sufficiently rapid to carry the air to the refrigerating coils without precipitation of moisture, and when the air comes in contact with the cold coils the moisture is deposited on the coils as ice. The result is a dry, pure air in the storage room.

In the average dairy cold-storage room satisfactory sizes for the air ducts are 15 per cent of the ceiling area for the warm-air duct and 10 per cent of the ceiling area for the cold-air duct. A typical single-bunker cold-storage room is shown in Figure 19, and a double-bunker room in Figure 20. The warm-air duct should extend at least to the height of the uppermost coil, and the discharge opening from the duct to the coils should be not less than the cross-sectional area of the warm-air duct.

In some cases the height of the room will not permit of an overhead bunker, and it becomes necessary to install the refrigerating coils on the walls of the room as illustrated in Figure 21. The rate of air circulation in this case is not so great as with overhead bunkers, and the coils occupy valuable storage space. Insulated baffles should be provided as shown to guide the air downward over all the coils and discharge it near the floor, thus cooling the air to as low a temperature as possible.

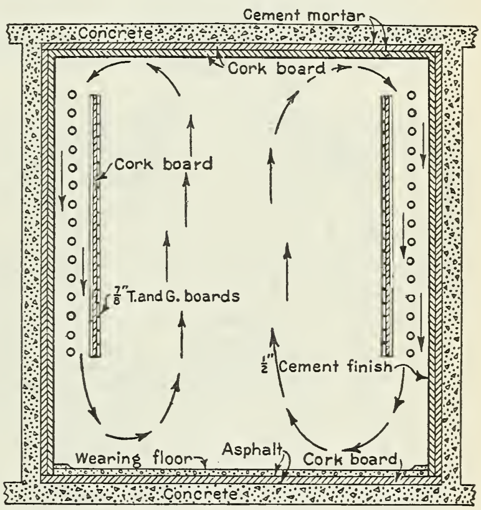

FIGURE 21.—Cold-storage rooms with refrigerating coils on the side walls

PHYSICAL PROPERTIES OF MILK AND MILK PRODUCTS IN RELATION TO COOLING

SPECIFIC HEAT

The specific heat of milk varies widely, depending upon the fat content and the temperature at which the determination is made. The specific heats of some dairy products are shown by the curves in Figure 22. It will be noted that they are greatest at about 67° F. and drop off rapidly both above and below this temperature. These high specific heats evidently are due to the change of state of the fats in the milk or cream. The range of greatest specific heat for milk and cream is from 50° to 75°, and this is partly within the

optimum range for the development of bacteria. Consequently, in designing cooling apparatus for dairy products, ample cooling surface should be provided to lower the temperature quickly through this critical stage.

The specific heats of other dairy products are approximately as follows:

Butter	0.56	Skim milk	0.95
Cheese	.64	Ice-cream mix:	
Condensed milk	.94	Above freezing	.9
Whey	.97	Below freezing	.46

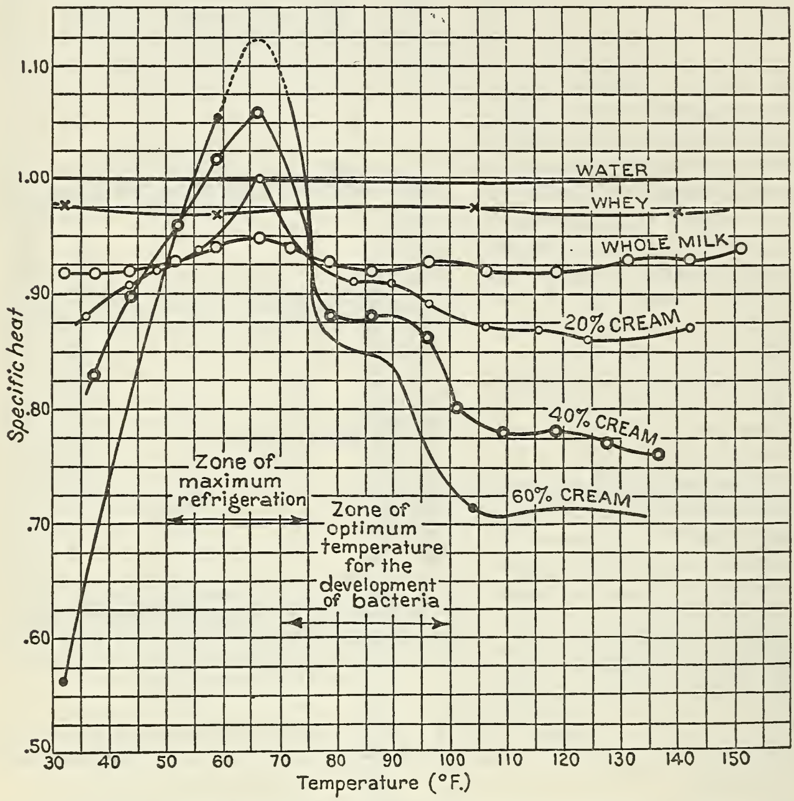

FIGURE 22.—Specific heats of some dairy products

SPECIFIC GRAVITY

The specific gravity of whole milk varies with its composition, temperature, and the length of time it is allowed to stand after milking; but it is always greater than water. The usual range is from 1.029 to 1.035. In the case of mixed-herd milk, 1.032 may be taken as an average, which corresponds to a weight of 8.59 pounds per gallon. Table 2 states the specific gravity of milk and cream at 68° F. in terms of water at the same temperature as unity. The values were determined by adding fat to skim milk, consequently through the range of normal milk the figures given are not absolutely correct.

TABLE 2.—*Specific gravity of milk and cream containing various percentages of butterfat at 68° F.*

Percentage of fat	Specific gravity	Percentage of fat	Specific gravity	Percentage of fat	Specific gravity	Percentage of fat	Specific gravity
0.025	1.037	11	1.024	21	1.012	31	1.003
1	1.036	12	1.022	22	1.011	32	1.002
2	1.035	13	1.020	23	1.010	33	1.001
3	1.034	14	1.019	24	1.009	34	1.000
4	1.032	15	1.018	25	1.008	35	.999
5	1.031	16	1.017	26	1.008	36	.999
6	1.030	17	1.016	27	1.007	37	.998
7	1.029	18	1.015	28	1.006	38	.997
8	1.027	19	1.014	29	1.005	39	.996
9	1.026	20	1.013	30	1.004	40	.995
10	1.025						

ADHESION

Adhesion increases as the temperature is lowered. Thus it is more difficult to clean, by means of water, a vessel that has contained cold milk than one that has contained warm milk.

VISCOSITY

Viscosity is possessed in a high degree by some milk products, such as cream and condensed milk, and affects considerably the heating and cooling of these products. When cream is run over a surface cooler, for example, as the temperature is lowered the viscosity increases, and the lower coils of the cooler are covered to a considerable depth. This covering acts as a heat insulator and greatly retards cooling. When cooling cream or condensed milk in a tank, this effect is even more marked, for such cooling is accomplished mostly by convection in the liquid itself. As the viscosity increases with lowering of the temperature, natural circulation of the liquid decreases and at low temperatures practically ceases. Then the transfer of heat from the cream to the cooling medium is largely by conduction, which is exceedingly slow because of the composition and arrangement of the fat globules. Therefore, apparatus for cooling viscous dairy products should be designed for forced convection.

AFFINITY

Milk and milk products have a strong affinity for most substances and will readily absorb large quantities of different gases, especially when the milk is warm. This absorption may be of either a chemical or a physical nature, or both. Therefore, gasoline and steam engines and refrigerating machines should be kept out of the room in which milk or any of its products are handled. Milk, cream, and butter always should be stored in a compartment by themselves, as they will absorb odors and flavors from practically all other food products.

FREEZING POINT

The freezing point of milk is the most constant of any of its physical properties. It varies slightly with the composition of the milk but is always lower than that of water. The freezing point of fresh, whole milk varies between 31.089° and 31.093° F. The addition of water serves to raise its freezing point toward that of water,

while the addition of soluble substances or an increase of acidity tends to lower the freezing point. Upon these variations in the freezing point is based the cryoscopical method of detecting the addition of water to milk.

The freezing point of evaporated milk is 29½° F., and that of sweetened condensed milk varies between 5° and 10½°, depending upon the composition and sugar content. There is no definite freezing point for butter; the degree of hardness increases as its temperature is lowered. Salted butter obviously will freeze at a lower temperature than unsalted, but both have comparatively low freezing points. The freezing point of cheese varies somewhat with the kind and lowers with the age of the cheese. The freezing points of some of the most common varieties of cheese are given in the following tabulation:[2]

	°F.		°F.
Cottage	29.8	Swiss (imported)	14.7
American (processed)	16.6	Swiss (domestic)	14.0
Limburger	18.7	Cheddar	8.8
Picnic Swiss (processed)	17.5	Roquefort	2.7
Brick	16.3		

Dried or powdered milk has such a low moisture content that for practical purposes it can be considered to have no freezing point.

The freezing point of ice-cream mixes varies with the composition of the mix. Table 3 gives the calculated freezing points of representative ice-cream mixes.

TABLE 3.—*Calculated freezing points of representative ice-cream mixes*[1]

Mix No.	Fat	Milk solids not fat	Sugar	Gelatin	Water	Freezing point
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	°*F.*
1	8.00	11.50	13.00	0.50	67.00	28.0
2	8.00	12.50	13.00	.50	66.00	27.9
3	8.50	12.00	13.00	.50	66.00	27.9
4	9.00	11.50	13.00	.50	66.00	27.9
5	10.00	10.50	14.00	.50	65.00	28.0
6	12.00	8.50	14.00	.50	65.00	28.2
7	12.00	9.50	14.00	.50	64.00	28.0
8	16.00	7.50	14.00	.50	62.00	28.2
9	18.00	7.50	14.00	.50	60.00	28.1
10	18.00	5.50	14.00	.50	62.00	28.7

[1] Adapted from the following publication: ASSOCIATES OF LORE A. ROGERS. FUNDAMENTALS OF DAIRY SCIENCE. 543 p., illus. New York. 1928. (Amer. Chem. Soc. Monograph [41].)

EFFECT OF FREEZING

When milk is frozen it is changed both in physical structure and in chemical composition. When milk is frozen in volume, as in the ordinary container, ice is formed first around the sides and at the bottom, most of the casein, sugar, and other mineral ingredients collect in the central part of the mass, and most of the fat gathers in the top layers. When the milk is thawed, clots composed mostly of albumen and fat are found floating in the liquid. Because of this separation of the constituent parts of milk, freezing for transportation has hitherto been little used. If milk is frozen quickly, however,

[2] WATSON, P. D., and LEIGHTON, A. SOME OBSERVATIONS ON THE FREEZING POINTS OF VARIOUS CHEESES. Jour. Dairy Sci. 10, 331–334, illus. 1927.

as by spraying on a revolving drum which is at a low temperature, this separation does not take place, and when thawed the milk apparently resumes its original state.

The effect of freezing upon evaporated milk is similar to that upon milk and cream. The effect of freezing upon cheese is to arrest the ripening prccess and to cause the cheese to crumble when thawed because of the expulsion of water at the time of freezing.

BOILING POINT

The boiling point of milk, like that of other liquids, varies according to the pressure to which the liquid is subjected, and also with its composition. Milk, being a compound, boils at a temperature approximately 1° F. higher than that of water under the same condition—at approximately 213° F. under the standard atmospheric pressure of 14.696 pounds per square inch. When concentrated by evaporation, the boiling point rises about 0.9° F. for every doubling of concentration; that is, if the ratio of concentration is 1 to 2 the boiling point rises 0.9° F., and if the concentration is 1 to 3 the boiling point rises 1.35° F.

EFFECT OF BOILING

Boiling produces marked physical and chemical changes in milk, some of which are: (1) lessens the amount of cream rising and collecting on the surface; (2) gives the milk a brown color and a cooked taste; (3) forms a scum on the surface; (4) coagulates the albumen; (5) decomposes the proteids; (6) precipitates the calcium and magnesium salts; (7) breaks up the fat globules; and (8) destroys the enzymes.

COEFFICIENT OF EXPANSION

Milk, like other liquids, expands and contracts with the changes in temperature. Often it is important to know what volume of milk must be measured out at an existing temperature in order to give a required volume at some standard temperature. The volumes of milk and cream at various temperatures occupied by a unit volume measured at 68° F. (20° C.) is given in Table 4.

TABLE 4.—*Volume*[1] *of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)*

Percentage of butterfat	Temperature (° F.)											
	50	52	54	56	58	60	62	64	66	68	70	72
	Volume.											
0.025	0.9980	0.9980	0.9985	0.9985	0.9990	0.9990	0.9990	0.9995	0.9995	1.0000	1.0000	1.0005
1	.9980	.9980	.9985	.9985	.9990	.9990	.9990	.9995	.9995	1.0000	1.0000	1.0005
2	.9975	.9975	.9980	.9980	.9985	.9990	.9990	.9995	.9995	1.0000	1.0000	1.0005
3	.9975	.9975	.9980	.9980	.9985	.9990	.9990	.9995	.9995	1.0000	1.0000	1.0005
4	.9975	.9975	.9980	.9980	.9985	.9985	.9990	.9995	.9995	1.0000	1.0000	1.0005
5	.9975	.9975	.9980	.9980	.9985	.9985	.9990	.9995	.9995	1.0000	1.0000	1.0005
6	.9970	.9975	.9975	.9980	.9980	.9985	.9990	.9995	.9995	1.0000	1.0000	1.0005
7	.9970	.9970	.9975	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0000	1.0010
8	.9970	.9970	.9975	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0005	1.0010
9	.9965	.9965	.9970	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0005	1.0010
10	.9965	.9965	.9970	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0005	1.0010
11	.9965	.9965	.9970	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0005	1.0010
12	.9955	.9960	.9965	.9970	.9975	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
13	.9955	.9960	.9965	.9970	.9975	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
14	.9950	.9955	.9960	.9970	.9975	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
15	.9950	.9955	.9960	.9970	.9975	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
16	.9950	.9955	.9955	.9965	.9970	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
17	.9945	.9950	.9955	.9965	.9970	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
18	.9940	.9945	.9950	.9960	.9970	.9980	.9980	.9985	.9990	1.0000	1.0005	1.0010
19	.9940	.9945	.9950	.9960	.9970	.9975	.9980	.9985	.9990	1.0000	1.0005	1.0010
20	.9930	.9940	.9945	.9955	.9965	.9975	.9980	.9985	.9990	1.0000	1.0005	1.0010
21	.9930	.9940	.9945	.9955	.9965	.9975	.9980	.9985	.9990	1.0000	1.0005	1.0010
22	.9930	.9940	.9945	.9955	.9965	.9975	.9980	.9985	.9990	1.0000	1.0010	1.0015
23	.9930	.9940	.9940	.9955	.9965	.9975	.9980	.9985	.9990	1.0000	1.0010	1.0015
24	.9925	.9930	.9940	.9950	.9960	9975	.9975	.9985	.9990	1.0000	1.0010	1.0015
25	.9925	.9930	.9940	.9950	.9960	.9970	.9975	.9985	.9990	1.0000	1.0010	1.0015
26	.9925	.9930	.9940	.9950	.9960	.9970	.9975	.9985	.9990	1.0000	1.0010	1.0015
27	.9925	.9930	.9940	.9950	.9960	.9970	.9975	.9985	.9990	1.0000	1.0010	1.0015
28	.9915	.9925	.9935	.9945	.9955	.9965	.9975	.9980	.9990	1.0000	1.0010	1.0115
29	.9915	.9925	.9935	.9945	.9955	.9965	.9975	.9980	.9990	1.0000	1.0010	1.0015
30	.9915	.9925	.9935	.9945	.9955	.9965	.9970	.9980	.9990	1.0000	1.0010	1.0020
31	.9915	.9925	.9935	.9945	.9955	.9965	.9970	.9980	.9990	1.0000	1.0010	1.0020
32	.9910	.9920	.9930	.9940	.9950	.9960	.9970	.9980	.9990	1.0000	1.0010	1.0020
33	.9910	.9920	.9930	.9940	.9950	.9960	.9970	.9980	.9990	1.0000	1.0010	1.0020
34	.9910	.9915	.9925	.9940	.9950	.9960	.9970	.9980	.9990	1.0000	1.0010	1.0020
35	.9900	.9915	.9925	.9940	.9940	.9960	.9970	.9980	.9990	1.0000	1.0010	1.0020
36	.9900	.9910	.9920	.9930	.9940	.9955	.9965	.9980	.9990	1.0000	1.0010	1.0025
37	.9890	.9910	.9920	.9930	.9940	.9955	.9965	.9980	.9990	1.0000	1.0010	1.0025
38	.9890	.9910	.9920	.9930	.9940	.9955	.9965	.9980	.9990	1.0000	1.0010	1.0025
39	.9890	.9900	.9915	.9925	.9940	.9955	.9965	.9975	.9990	1.0000	1.0010	1.0025
40	.9890	.9900	.9915	.9925	.9940	.9950	.9960	.9975	.9990	1.0000	1.0010	1.0025

[1] The tabulated values are given to the nearest 0.0005.

TABLE 4.—*Volume of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)*—Continued

Percentage of butterfat	Temperature (° F.)											
	74	76	78	80	82	84	86	88	90	92	94	96
	Volume											
0.025	1.0005	1.0010	1.0010	1.0015	1.0020	1.0025	1.0030	1.0030	1.0035	1.0040	1.0045	1.0050
1	1.0005	1.0010	1.0010	1.0015	1.0020	1.0025	1.0030	1.0030	1.0035	1.0040	1.0045	1.0050
2	1.0010	1.0010	1.0015	1.0020	1.0020	1.0025	1.0030	1.0035	1.0040	1.0040	1.0045	1.0050
3	1.0010	1.0010	1.0015	1.0020	1.0020	1.0025	1.0030	1.0035	1.0040	1.0045	1.0045	1.0055
4	1.0010	1.0010	1.0015	1.0020	1.0020	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0055
5	1.0010	1.0015	1.0020	1.0020	1.0025	1.0030	1.0035	1.0035	1.0045	1.0045	1.0050	1.0055
6	1.0010	1.0015	1.0020	1.0020	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0050	1.0060
7	1.0010	1.0015	1.0020	1.0025	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0055	1.0060
8	1 0010	1.0015	1.0020	1.0025	1.0030	1.0030	1.0035	1.0040	1.0045	1.0050	1.0055	1.0060
9	1.0010	1.0015	1.0020	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0055	1.0060	1.0065
10	1.0015	1.0020	1.0025	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0055	1.0060	1.0065
11	1.0015	1.0020	1.0025	1.0025	1.0030	1.0035	1.0040	1.0045	1.0055	1.0055	1.0065	1.0070
12	1.0015	1.0020	1.0025	1.0030	1.0030	1.0035	1.0040	1.0050	1.0055	1.0060	1.0065	1.0070
13	1.0015	1.0020	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0055	1.0060	1.0065	1.0070
14	1.0015	1.0020	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0055	1.0065	1.0070	1.0075
15	1.0015	1.0025	1.0030	1.0030	1.0035	1.0040	1.0045	1.0055	1.0060	1.0065	1.0070	1.0075
16	1.0015	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0055	1.0060	1.0070	1.0075	1.0080
17	1.0015	1.0025	1.0030	1.0035	1.0040	1.0045	1.0050	1.0060	1.0060	1.0070	1.0075	1.0080
18	1.0020	1.0025	1.0030	1.0035	1.0040	1.0045	1.0055	1.0060	1.0065	1.0075	1.0080	1.0085
19	1.0020	1.0025	1.0030	1.0035	1.0045	1.0045	1.0055	1.0060	1.0065	1.0075	1.0080	1.0085
20	1.0020	1.0025	1.0030	1.0035	1.0045	1.0050	1.0055	1.0060	1.0070	1.0075	1.0085	1.0090
21	1.0020	1.0025	1.0030	1.0040	1.0045	1.0050	1.0060	1.0065	1.0070	1.0080	1.0085	1.0090
22	1.0020	1.0030	1.0035	1.0040	1.0050	1.0055	1.0060	1.0065	1.0075	1.0080	1.0090	1.0095
23	1.0020	1.0030	1.0035	1.0040	1.0050	1.0055	1.0065	1.0070	1.0075	1.0085	1.0090	1.0095
24	1.0020	1.0030	1.0035	1.0040	1.0050	1.0060	1.0065	1.0070	1.0080	1.0085	1.0095	1.0100
25	1.0020	1.0030	1.0035	1.0045	1.0055	1.0060	1.0070	1.0075	1.0080	1.0090	1.0095	1.0105
26	1.0025	1.0030	1.0040	1.0045	1.0055	1.0060	1.0070	1.0080	1.0085	1.0090	1.0100	1.0110
27	1.0025	1.0030	1.0040	1.0045	1.0055	1.0060	1.0070	1.0080	1.0085	1.0095	1.0100	1.0110
28	1.0025	1.0030	1.0040	1.0045	1.0055	1.0065	1.0075	1.0080	1.0090	1.0095	1.0105	1.0115
29	1.0025	1.0030	1.0040	1.0050	1.0060	1.0065	1.0075	1.0080	1.0090	1.0095	1.0105	1.0115
30	1.0025	1.0035	1.0045	1.0050	1.0060	1.0065	1.0080	1.0085	1.0095	1.0100	1.0110	1.0120
31	1.0025	1.0035	1.0045	1.0050	1.0060	1.0065	1.0080	1.0085	1.0095	1.0100	1.0110	1.0120
32	1.0030	1.0035	1.0045	1.0055	1.0065	1.0070	1.0085	1.0090	1.0100	1.0105	1.0115	1.0125
33	1.0030	1.0035	1.0045	1.0055	1.0065	1.0070	1.0085	1.0090	1.0100	1.0105	1.0115	1.0125
34	1.0030	1.0040	1.0050	1.0055	1.0065	1.0075	1.0085	1.0095	1.0105	1.0110	1.0120	1.0130
35	1.0030	1.0040	1.0050	1.0060	1.0070	1.0075	1.0090	1.0095	1.0105	1.0110	1.0120	1.0130
36	1.0035	1.0045	1.0055	1.0060	1.0070	1.0080	1.0090	1.0100	1.0110	1.0115	1.0125	1.0135
37	1.0035	1.0045	1.0055	1.0060	1.0070	1.0080	1.0095	1.0100	1.0110	1.0115	1.0125	1.0135
38	1.0035	1.0045	1.0055	1.0065	1.0075	1.0085	1.0095	1.0100	1.0115	1.0120	1.0130	1.0140
39	1.0035	1.0045	1.0055	1.0065	1.0075	1.0085	1.0095	1.0105	1.0115	1.0120	1.0130	1.0140
40	1.0035	1.0045	1.0055	1.0065	1.0075	1.0085	1.0095	1.0105	1.0115	1.0125	1.0130	1.0145

TABLE 4.—*Volume of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)*—Continued

Percentage of butter fat	Temperature (° F.)										
	98	100	102	104	106	108	110	112	114	116	118
	Volume										
0.025	1.0055	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105
1	1.0055	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105
2	1.0055	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0110
3	1.0060	1.0065	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0110
4	1.0060	1.0065	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0110
5	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0085	1.0090	1.0095	1.0100	1.0110
6	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0090	1.0095	1.0100	1.0110
7	1.0065	1.0070	1.0075	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0115
8	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115
9	1.0065	1.0070	1.0080	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115
10	1.0070	1.0075	1.0080	1.0085	1.0090	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115
11	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0095	1.0100	1.0105	1.0110	1.0115
12	1.0075	1.0080	1.0085	1.0090	1.0095	1.0095	1.0105	1.0110	1.0115	1.0120	1.0125
13	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115	1.0120	1.0125
14	1.0080	1.0085	1.0090	1.0095	1.0100	1.0100	1.0110	1.0115	1.0120	1.0125	1.0130
15	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115	1.0120	1.0125	1.0130
16	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115	1.0120	1.0125	1.0130	1.0135
17	1.0085	1.0090	1.0095	1.0105	1.0105	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140
18	1.0090	1.0095	1.0100	1.0105	1.0110	1.0120	1 0125	1.0130	1.0135	1.0140	1.0145
19	1.0090	1.0095	1.0100	1.0110	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145
20	1.0095	1.0100	1.0105	1.0110	1.0115	1.0125	1.0130	1.0135	1.0140	1.0145	1.0150
21	1.0095	1.0100	1.0105	1.0115	1.0120	1.0125	1.0130	1.0135	1.0145	1.0150	1.0155
22	1.0100	1.0105	1.0110	1.0120	1.0125	1.0130	1.0135	1.0140	1.0150	1.0155	1.0160
23	1.0105	1.0105	1.0115	1.0120	1.0125	1.0130	1.0140	1.0145	1.0150	1.0155	1.0160
24	1.0105	1.0110	1.0120	1.0125	1.0130	1.0135	1.0145	1.0150	1.0155	1.0160	1.0165
25	1.0110	1.0115	1.0120	1.0130	1.0135	1.0140	1.0145	1.0150	1.0160	1.0165	1.0170
26	1.0115	1.0120	1.0125	1.0135	1.0140	1.0145	1.0155	1.0160	1.0165	1.0170	1.0180
27	1.0115	1.0120	1.0130	1.0135	1.0140	1.0150	1.0155	1.0160	1.0170	1.0170	1.0180
28	1.0120	1.0125	1.0130	1.0140	1.0145	1.0150	1.0160	1.0165	1.0175	1.0175	1.0185
29	1.0120	1.0130	1.0135	1.0140	1.0150	1.0155	1.0160	1.0165	1.0175	1.0180	1.0185
30	1.0125	1.0130	1.0135	1.0145	1.0155	1.0155	1.0165	1.0170	1.0175	1.0180	1.0190
31	1.0125	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175	1.0180	1.0185	1.0190
32	1.0130	1.0135	1.0140	1.0150	1.0160	1.0165	1.0170	1.0180	1.0185	1.0190	1.0195
33	1.0130	1.0140	1.0145	1.0155	1.0160	1.0165	1.0170	1.0180	1.0185	1.0190	1.0195
34	1.0135	1.0140	1.0150	1.0160	1.0165	1.0170	1.0175	1.0185	1.0190	1.0195	1.0200
35	1.0135	1.0145	1.0150	1.0160	1.0165	1.0170	1.0180	1.0190	1.0195	1.0200	1.0205
36	1.0140	1.0145	1.0155	1.0165	1.0170	1.0175	1.0185	1.0195	1.0200	1.0205	1.0210
37	1.0145	1.0150	1.0160	1.0165	1.0175	1.0180	1.0185	1.0195	1.0200	1.0205	1.0210
38	1.0150	1.0155	1.0165	1.0170	1.0175	1.0185	1.0190	1.0200	1.0210	1.0215	1.0215
39	1.0150	1.0160	1.0165	1.0170	1.0180	1.0185	1.0195	1.0205	1.0210	1.0215	1.0220
40	1.0155	1.0165	1.0170	1.0175	1.0185	1.0190	1.0200	1.0210	1.0215	1.0220	1.0230

TABLE 4.—*Volume of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)*—Continued

Percentage of butter fat	Temperature (° F.)										
	120	122	124	126	128	130	132	134	136	138	140
	Volume										
0.025	1.0110	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
1	1.0110	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
2	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
3	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
4	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
5	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
6	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
7	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0170	1.0175
8	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0165	1.0170	1.0175
9	1.0120	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0180
10	1.0120	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0180
11	1.0120	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0180
12	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180
13	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180
14	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185
15	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185
16	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190
17	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0175	1.0180	1.0185	1.0190
18	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0185	1.0190	1.0195
19	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0185	1.0190	1.0195
20	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190	1.0195	1.0200	1.0205
21	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190	1.0190	1.0195	1.0200	1.0205
22	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190	1.0190	1.0195	1.0200	1.0205	1.0210
23	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190	1.0195	1.0195	1.0200	1.0205	1.0210
24	1.0170	1.0180	1.0185	1.0190	1.0195	1.0200	1.0205	1.0205	1.0210	1.0215	1.0220
25	1.0175	1.0180	1.0185	1.0190	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225
26	1.0185	1.0190	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235
27	1.0185	1.0190	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235
28	1.0190	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245
29	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245
30	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0235	1.0240	1.0245	1.0250
31	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250
32	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255
33	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255
34	1.0210	1.0215	1.0220	1.0225	1.0230	1.0240	1.0245	1.0245	1.0250	1.0255	1.0260
35	1.0210	1.0215	1.0220	1.0225	1.0230	1.0240	1.0245	1.0250	1.0250	1.0255	1.0260
36	1.0215	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255	1.0260	1.0265	1.0270
37	1.0215	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255	1.0260	1.0265	1.0270
38	1.0220	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255	1.0260	1.0265	1.0270	1.0280
39	1.0225	1.0235	1.0240	1.0245	1.0250	1.0255	1.0260	1.0265	1.0270	1.0275	1.0280
40	1.0235	1.0240	1.0245	1.0255	1.0260	1.0265	1.0270	1.0275	1.0280	1.0285	1.0290

RELATION OF TEMPERATURE TO BACTERIAL AND CHEMICAL CHANGES IN MILK

The temperature at which most bacteria found in milk multiply with greatest rapidity is from 70° to 100° F. Below 70° the rate of growth diminishes rapidly with lowering of the temperature.

An illustration of the effect that a few degrees reduction in temperature will have in retarding the development of bacteria in milk is given by Figure 23 which shows the result of a survey made of 102 dairy farms. Samples of milk were taken, and bacterial counts were made. Instructions were given in the handling of the milk, particularly emphasizing the importance of rapid and thorough cooling. Later the same dairies were again visited and bacterial counts made as before. The results are shown in Figure 23. The great decrease in the number of bacteria found in the second survey was largely due to the prevention of bacterial development by keeping the milk at a lower temperature. The chart shows an average

temperature of 62° F. for all samples taken before instructions were given, and an average of 54° after instructions were given. Due primarily to this drop of only 8° F., the average bacterial count was reduced from 27,000,000 per cubic centimeter to 750,000 per cubic centimeter, a reduction of 36 to 1. For the 18 poorest dairies,

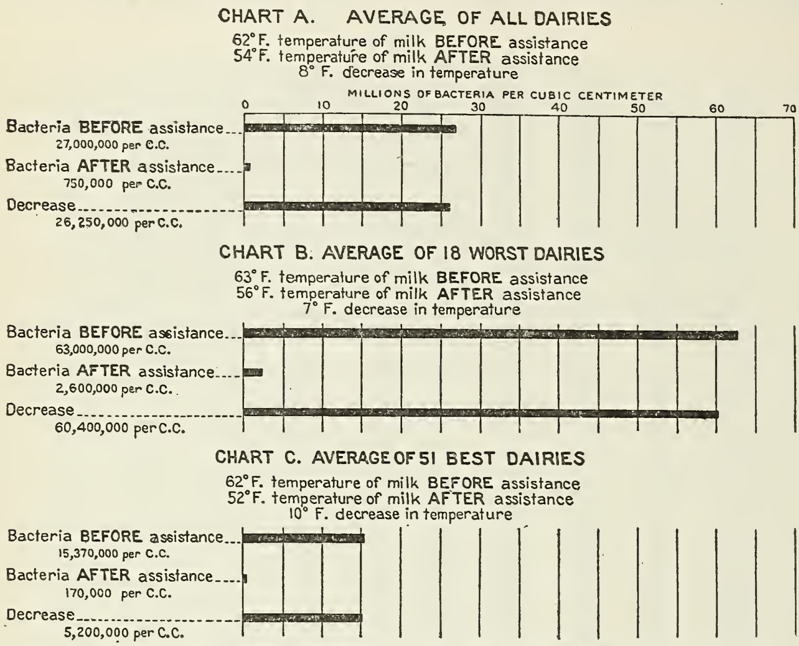

FIGURE 23.—Improvement in milk from 102 dairies after assistance from the United States Department of Agriculture

the average decrease in temperature was 7°, from 63° to 56°, and the reduction was 24 to 1. For the 51 best dairies, the average decrease in temperature was 10°, from 62° to 52°, and the reduction was 90 to 1.

The influence of time in conjunction with temperature, on bacterial growth in milk is clearly shown in Table 5.[3]

TABLE 5.—*Increase in number of bacteria in milk held at different temperatures*

Temperature of milk	Relative number of bacteria when the period of holding was—				
	0 hour	6 hours	12 hours	24 hours	48 hours
50° F.	1	1.2	1.5	4.1	6.2
68° F.	1	1.7	24.2	6,128.0	357,499.0

At or below the freezing point some types of bacteria develop, though the rate of development is slow; with a good quality of milk it may be weeks or even months before they attain great headway.

[3] ROGERS, L. A. BACTERIA IN MILK. U. S. Dept. Agr. Farmers' Bul. 490, 23 p., illus. 1912.

The bacteria that grow at low temperatures are of a different variety from those ordinarily found in milk at higher temperatures. They may produce marked changes in the chemical composition of the milk without especially changing its appearance, taste, or odor.

Experiments have been conducted to determine the resistance of bacteria to extremely low temperatures obtained by means of liquid air. The milk was maintained at these temperatures for several hours, but when the milk was thawed the bacteria were viable. Apparently low temperatures will not destroy bacteria though they will cause most kinds to lie dormant. Different kinds of bacteria become dormant at different temperatures, consequently the sensitiveness of the particular variety of bacteria to the effect of low temperature governs the degree of cooling that should be applied. Ordinarily dairymen are concerned only with the lactic acid-forming bacteria, which may be satisfactorily controlled at temperatures above the freezing point of milk.

At temperatures above 145° F., important chemical changes take place in milk, and these changes are intensified as the time is prolonged or the temperature increased. These changes consist chiefly in altering the casein, coagulating the albumin, decomposing the sugar, and precipitating some of the salts. The milk acquires a cooked taste, its color is deepened, and a scum is formed on the surface. At low temperatures no important chemical changes take place unless the milk is held for a considerable length of time, and as the result of bacterial action already discussed.

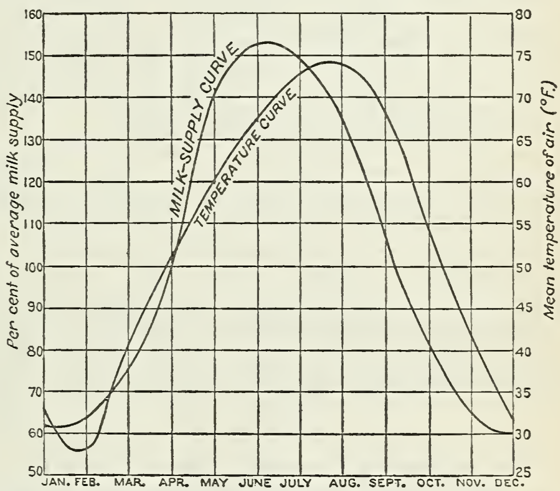

FIGURE 24.—Variation in milk production and in temperature of the air

It will be noted from the foregoing that time as well as temperature affects bacterial growth and chemical changes. Low temperatures do not prevent chemical and bacteriological changes in milk, but they serve to greatly retard such changes. Milk deteriorates in time regardless of the temperature at which it is held, but the period required varies with the temperature as well as with the initial cleanliness and purity of the milk.

SEASONAL VARIATION IN MILK PRODUCTION

The average volume of milk produced daily, weekly, or monthly varies over a wide range during the year, as illustrated in Figure 24. These variations are due largely to the variation in the amount

of grass and other succulent foods, which in turn vary almost directly with the temperature. The quantity of refrigeration required in a dairy plant increases both with the air temperature and with the quantity of milk. It is very important, therefore, in determining the capacity of the refrigerating equipment, to take into consideration the seasonal variations in the milk supply. The volume of milk produced annually in the United States has been estimated in excess of 123,000,000,000 pounds.

USES OF REFRIGERATION IN THE DAIRY INDUSTRY

It is generally recognized that milk should be cooled as quickly as possible after it has been drawn from the cow and should be held at a temperature sufficiently low to prevent the rapid development of bacteria until it is consumed. Many States and cities have promulgated laws and ordinances specifying the highest temperature that will be allowed for milk when delivered to market, and the temperature must be lowered below that specified so it will not exceed the limit when the milk is delivered.

While the development of bacteria in milk for the first two or three hours after milking is slow, and cooling might be delayed for an hour or two after milking without inducing the rapid multiplication of bacteria that would occur later at similar temperatures, nevertheless it is extremely important that the heat be removed quickly after milking. The nearer the temperature of milk approaches the freezing point, the longer the time it can be held in a wholesome condition, but it should not be allowed to freeze because freezing changes its physical properties. The cost of cooling and holding milk increases, however, as the temperature is lowered.

COOLING MILK ON THE FARM

The methods of cooling milk on the farm and of holding it at a low temperature while transporting it to the receiving station or milk plant are, in general, greatly in need of improvement. Proper cooling of milk on the farm generally is difficult because of limited time and lack of proper facilities. Insufficient cooling on the farm and inadequate means of keeping the milk cool during transportation to the factory are responsible for much of the spoiled milk. At the receiving station or factory, equipment is usually available for thorough cooling and for maintenance of low temperatures.

Many methods for cooling milk are employed on the farm, ranging from the crude method of placing the cans of warm milk in spring or well water to modern mechanical refrigeration in connection with water or brine tanks. The temperature of surface and shallow-well waters in the more northern States may be sufficiently low to cool milk properly during the winter months, but the temperatures of such waters generally are too high to cool milk sufficiently, especially during the warmer months. Deep well and spring water, however, can often be employed to advantage for cooling milk through the higher temperature ranges, even though cooling to the final low temperature is to be accomplished with ice water or with refrigerated water or brine.

The greater portion of the milk supply of the country is produced where natural ice can be harvested, and with proper care in storing, handling, and application it can be used satisfactorily for cooling milk. There are disadvantages, however, in the use of natural ice, such as the cost of harvesting and storing it, the disagreeable work of getting it from storage, and washing it for use, the extra time consumed in handling it, the slop incident to its use, and the considerable care sometimes necessary to obtain satisfactorily low milk temperatures. Because of the extra and disagreeable work in handling the ice, dairymen have often neglected to cool the milk properly. Where natural ice is not available, manufactured ice is often employed. But the initial cost, the cost of hauling, and loss through melting makes its use expensive and hence is an incentive for economizing in the quantity used at the expense of adequate cooling of the milk. Mechanical refrigeration avoids many of the disadvantages incident to the use of ice, and the cost compares favorably with the cost of refrigeration with ice. The increasing use of electricity on the farm has given an impetus to the use of mechanical refrigeration, as it is safe, reliable, lends itself admirably to automatic control, and requires a minimum of attendance.

The two types of cooling equipment for cooling milk now in general use on farms are the storage-tank type and the dry-box type.

STORAGE-TANK TYPE OF EQUIPMENT

In its simplest form, the storage-tank equipment is merely a tank filled with cold water, into which cans of milk are set to cool. Preferably, the tank is insulated. Generally, the water is cooled before the milk is placed in it, either by adding ice or by mechanical refrigeration. For the average dairy farm handling milk in 10-gallon cans, this is undoubtedly the most economical and satisfactory type of cooling equipment. Figure 25 illustrates a tank of this type, which may be used with either ice or mechanical refrigeration.

The milk may be cooled in the storage tank through the entire temperature range, from that at which it comes from the cow to the final temperature desired, or it may first be partly cooled through a surface cooler that will remove the greater part of the heat quickly. When cooled entirely in the tank, the time required often is so great that it interferes with other work and with getting the milk to its destination on schedule time. If the milk is stirred during cooling, the time required is greatly lessened, as shown in Figure 26. When run over a surface cooler, where the milk is spread out in a thin layer, the time required is greatly reduced, but because the milk is exposed, some additional bacteria may be collected from the air. It is believed, however, that the employment of a surface cooler is advantageous.

When the water in the tank is cooled artificially, the initial quantity should be as small as practicable consistent with effective operating conditions, because of the cost or the labor of removing the heat originally contained in it. Of course, ample space must be provided for ice, if ice is used, and for free circulation of water around the cans, and there must be a sufficient volume of water to hold down the

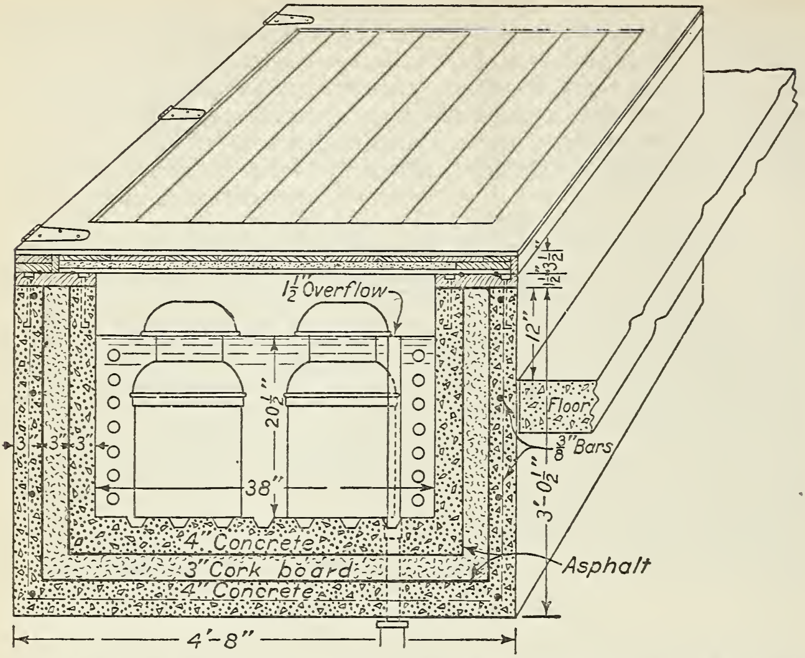

FIGURE 25.—Insulated, concrete, milk-cooling tank, with refrigerating coils at sides. For cooling with ice, the coils may be omitted

temperature of the milk for a reasonable time after the ice has melted. Generally the volume of water should be about three times that of the milk.

DRY-BOX TYPE OF EQUIPMENT

The dry-box type of cooling installation is somewhat more elaborate than the storage-tank type just described, because ordi-

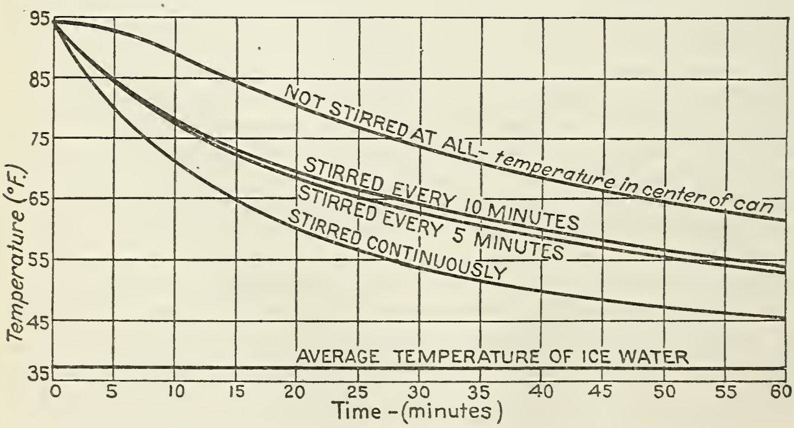

FIGURE 26.—Rate of cooling milk in 10-gallon cans placed in ice water

narily it involves the use of brine. A typical farm cooling plant of this type is shown in Figure 27.

The dry-box type of storage consists of a brine tank located in the upper part of an insulated compartment. The cold brine is circulated from this tank through a surface milk cooler, by means of a pump, and returned to the tank. The milk as it comes from the surface cooler is caught in cans, which are placed in the compartment where the desired temperature is maintained, or the milk from the surface cooler may be bottled before being placed in the storage compartment. The brine tank serves the double purpose of providing refrigeration for operating the milk cooler and for holding down temperatures in the storage compartment. The brine tank is uninsulated, and the metal surface of the tank absorbs the heat from the air in the compartment. Where the milk is to be stored in bottles, this dry-box storage is believed to be better than the storage-tank type.

SIZE OF REFRIGERATING PLANT

In estimating the size of refrigerating plant for cooling milk on the farm, there are many details to be considered, such as: (1) The quantity of milk to be cooled; (2) the temperature range through which it must be cooled; (3) the time available for cooling; (4) the length of time the milk is to be held in storage; (5) the temperature of the air; (6) the amount and kind of insulation to be used; (7) the length of time the refrigerating machine is to be operated; (8) the method of storing, whether in 10-gallon cans or in bottles; and (9) the type of storage equipment, whether a tank of water or refrigerated room.

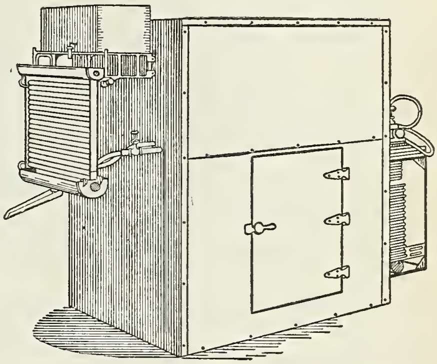

FIGURE 27.—Dry-box type of milk-cooling installation, including surface cooler and mechanical refrigeration

The cooling of milk on the farm generally is done in two periods, night and morning. The time allotted is usually that required for milking. The milk is taken immediately from the barn to the cooler, where it is reduced from body temperature to around 45° F. Shortly after the milking is finished, the cooling operation is completed. The time available for cooling is usually 1 to 1½ hours for each milking, consequently ample refrigeration must be available to do the work in this time. The general practice includes storage of sufficient refrigeration in a tank of water or brine. The refrigerated water, or brine, is circulated through a surface cooler where the temperature of the milk is quickly reduced. The milk from the cooler is caught in cans for storage or immediate transportation to market. The night's milk, after being run over the cooler, is stored overnight either in the tank of cold water or in a storage box or room where the temperature is further reduced. The morning's milk may be immediately started on its way to market, hence greater care is taken

in its cooling in order to insure its temperature being sufficiently low to arrive at its destination in good condition.

Where possible, the milk should be precooled. Some dairymen cool the milk by running cold well or spring water through the upper half of a 2-section surface cooler, and refrigerated water or brine through the lower half. By using cold spring or well water for partial cooling of the milk a reduction of 30 to 40 per cent in the capacity of the machine may be effected in removing the animal heat. Since cooling with water is much cheaper than cooling by means of mechanical refrigeration, it should be employed to the full extent of its cooling capacity. The night's milk may be partly cooled by using cold well or spring water in the surface cooler, and then setting the cans in the cooling tank or room overnight where the milk is further cooled. In this case the milk should be run over the cooler very slowly, so that water will cool it to as low a temperature as possible before it is placed in storage to lower the temperature before considerable bacterial development occurs. Especially is this care needed with dry-box storage because milk cools more slowly in air than in water. The lower the temperature to which milk is cooled the better, so long as it does not freeze.

Milk production ordinarily is greatest in June and least in December, while in April and September it approximates the average for the year. (Fig. 24.) The maximum is about 50 per cent greater than the average for the year; on some farms the maximum has been more than double the yearly average. (On a few farms the seasonal variation is being changed to some extent by feeding and by causing the freshening of the cows to occur in the winter months.) In determining the capacity of the refrigerating machine, consideration should be given to the maximum production.

Ample machine capacity should be provided. To install a small machine and to operate it for 15 or 18 hours per day is a mistake. A small machine operated for long periods has a much shorter life than a larger machine running for shorter periods. Furthermore, the efficiency of a large machine is considerably greater than that of a small one, and the cost of producing a unit of refrigeration with a large machine is considerably less than with a small one. (Fig. 28.) The difference in the initial costs of the two machines would soon be made up by the difference in cost of operation, even disregarding the greater wear and tear and resulting shorter life of the smaller machine.

The cooling of milk on the farm demands a large amount of refrigeration for a short time only. A large-capacity machine is better adapted to such work than a small machine, because with the small machine greater storage capacity is required with a greater heat-transmitting surface. The consequently greater heat leakage necessitates operating the machine for longer periods. In most instances the dissatisfaction with mechanical refrigeration on the farm can be traced to insufficient capacity. The first cost of a machine able to perform the work in a comparatively short time is not much greater than that of a small machine that will require many more hours of operation to do the same work. Many of the machines now installed on dairy farms are too small to perform satisfactorily and economically the work required of them.

TRANSPORTATION OF MILK

Considerable attention has been given in the last few years to maintaining milk at lower temperatures during transportation. The greatest loss of milk in the past probably has been due to inadequate cooling on the farm and failure to maintain sufficiently low temperatures en route to prevent bacterial development.

Only a few years ago the greater part of the milk consumed in the cities was transported from the farms in wagons, or in ordinary baggage cars, or on the interurban electric railways, with no provision made for holding the milk at low temperatures. The milk was for the most part inadequately cooled on the farm, and often it remained at railroad sidings exposed to the sun for hours before being placed aboard the cars.

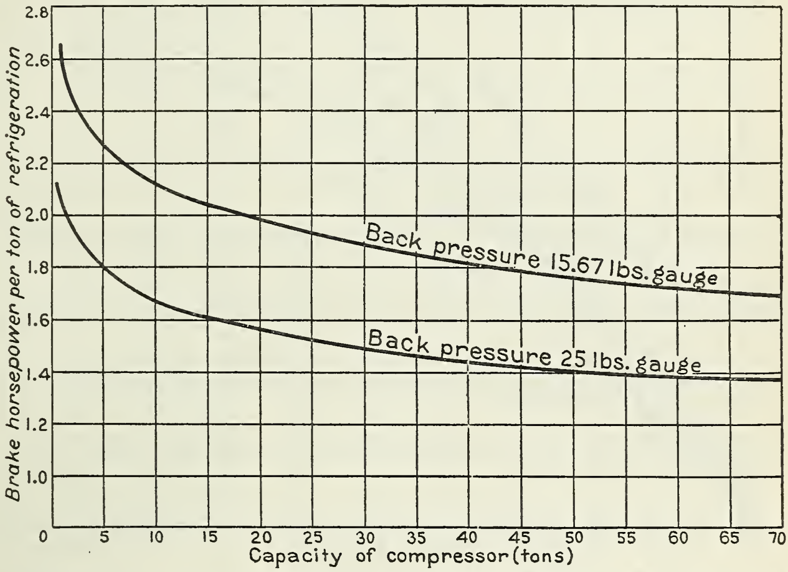

FIGURE 28.—Variation in power required per ton of refrigeration with capacity of machine for compression refrigerating systems; condensing pressure 185 pounds gauge, when ammonia is used as the refrigerant

The first step toward maintaining low temperatures in transit was to employ insulating jackets, which were drawn tightly over the cans. This materially retarded the rise in temperature of the milk and was a distinct move in the right direction. The second step was to partly line the ordinary baggage car with galvanized iron, and pack ice around the cans of milk in it. This was expensive and unsatisfactory, and soon led to the construction of a car designed especially for transporting milk.

This specially designed car constituted the third step in keeping milk cold en route. It was a well-insulated car for shipping milk in cans or other portable containers and was provided with bunkers or tanks for ice. The bunkers were located at the ends of the car, and the ratio of ice capacity to the loading capacity of the car was about 3½ pounds of ice per gallon of milk. Later designs of these cars

employed a mixture of salt and ice, and thus obtained lower temperatures than with ice alone. These cars proved satisfactory for comparatively short hauls, and with certain modifications and improvements are largely employed at the present time.

Among the latest developments in equipment for the transportation of milk is the insulated tank, mounted either in a specially designed railway car or on an automobile truck. The cold milk is pumped from the storage tanks in the receiving station into the car tanks, and the car is tightly closed. In some cases the milk is run directly from the coolers into the car tanks. It is important to completely fill the tanks with the cold milk in order to prevent

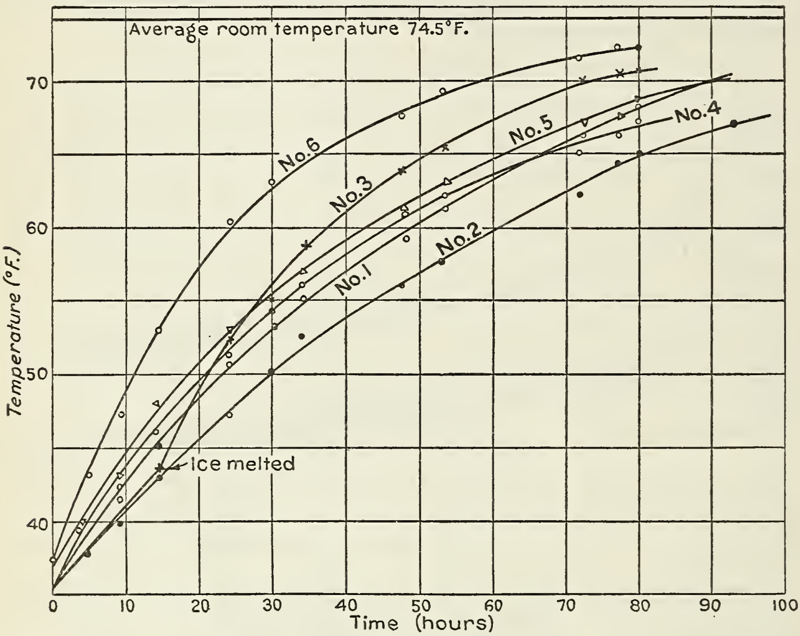

FIGURE 29.—Effect of types of insulation upon temperature of milk in 10-gallon cans in room held at 74.5° F.; No. 1, insulated can. ½-inch cork; No. 2, insulated can, 1-inch cork; No. 3, ice-compartment can; No. 4, can with 1-inch felt jacket; No. 5, can with ½-inch felt jacket; No. 6, uninsulated can

splashing and agitation due to the movement of the car, which results in a partial churning of the milk and a more rapid rise in temperature. The car is equipped with a special ventilating system, stationary milk pump or air pressure for unloading, water reservoir for washing tanks and cars in case water is not available at the railroad siding, and with electric lights, switches, motors, etc. The tanks themselves are equipped with agitators and 2-speed electric motors, electric lights, observation glasses, air vents, etc. After being emptied of milk the tanks are thoroughly washed, then they are closed and steam under pressure is admitted for the purpose of destroying the greater portion of the bacteria, or a chlorine solution is used for the same purpose.

Practically none of the equipment in use at the present time for transportation of milk is designed for lowering the temperature of

the milk during transit but simply to maintain low temperatures. It it assumed in all cases that the milk has been properly cooled before it is delivered for transportation. Recently considerable attention has been given to installing refrigerating equipment directly in the car, and a type of car employing a compression system of refrigeration has been developed in which the compressor is driven from the car axle. There is also a car in service employing the absorption system of refrigeration.

Besides the insulated-tank trucks extensively used for short hauls, there are several types of heavily insulated and refrigerated body trucks in service. Refrigeration is provided by ice and salt mixtures, solid carbon dioxide, or cartridges containing a liquid mixture having a freezing temperature considerably below that of water. The cartridges are frozen solid in a low-temperature room or brine tank and placed in overhead compartments of the truck. Individual refrigerating plants are employed to a limited extent in trucks for the transportation of milk and other dairy products. An experimental tank truck has recently been designed for receiving fresh milk and cooling it during transportation.

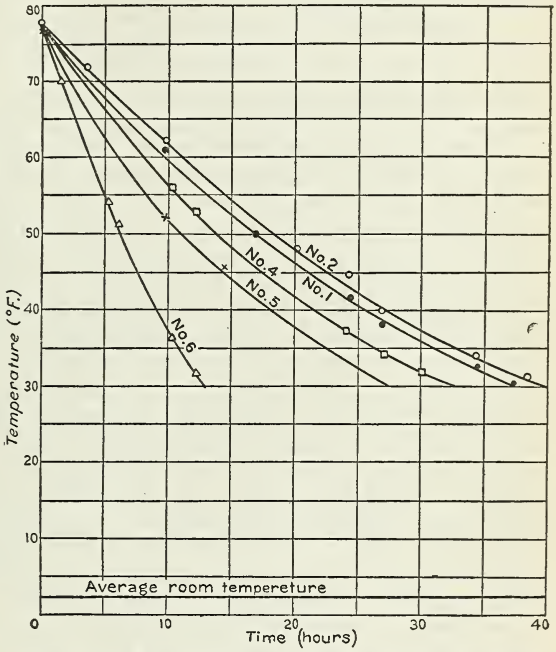

FIGURE 30.—Effect of types of insulation upon temperature of milk in 10-gallon cans in room held near 0° F.; No. 1, insulated can, ½-inch cork; No. 2, insulated can, 1-inch cork; No. 4, can with 1-inch felt jacket; No. 5, can with ½-inch felt jacket; No. 6, uninsulated can

There are a number of means devised for retarding the rise in temperature of milk in the shipping cans, though they are not used extensively. They consist of insulating the cans by means of jackets, by building the insulation in the cans themselves, or by providing an ice compartment within the can. Results of tests of different types of such cans are shown in Figure 29. Insulated cans are also a protection against freezing of the milk. Results of tests of insulated cans against freezing are shown in Figure 30.

Cans of milk should always be protected from the direct rays of the sun. The temperature of the can surface when exposed to the sun will be several degrees higher than that of the surrounding air. The radiant heat from the sun in summer will amount to from 3 to 5 British thermal units per minute per square foot of surface, which alone is sufficient to raise the temperature of the milk materially.

Therefore provision should be made for protecting the cans from the sun's rays at railroad sidings and pick-up stations.

RECEIVING STATIONS

A receiving station receives, cools, and handles milk preparatory to shipping it to the city plant. Such stations are located at suitable points on the railroads or highways, depending on whether the milk is to be transported by railway trains or by motor trucks. The milk is brought to the receiving station from the surrounding farms each morning, is sampled and tested, and rejected if not in good condition. That not rejected is immediately cooled and prepared for shipping to the city plant.

Where the milk is to be cooled and prepared for shipment in a few hours after it is received the equipment of the station need be only that necessary for weighing and cooling the milk and for washing and treating the farm cans to kill bacteria. However, to guard against loss in case of delays in railroad or truck service or in case of a temporary breakdown of the cooling equipment, a cold-storage room is often provided, or insulated storage tanks, of sufficient capacity to store the milk received in one or two days. Other receiving stations are quite elaborate establishments provided with pasteurizers, bottling machines, separators, churns, cream-ripening vats, condensing pans, etc. Such equipment is installed for the purpose of making the best possible disposition of the surplus milk received during the season of large production, by converting it into a product best suited to the market at the time.

The capacity of the cooling equipment in the receiving station should be ample to handle the maximum milk supply in the time available for cooling, which usually is limited by train or truck schedules. A large amount of refrigeration must therefore be provided for quick action when needed. This is accomplished either by installing a refrigerating machine of large capacity relative to the amount of milk to be handled, or by installing a smaller machine and operating it a longer time and storing refrigeration in brine or water. Both methods are employed, each having its advantages according to the size of plant and local conditions.

Most of the milk is shipped from the receiving station to the city plant in bulk, either in insulated-tank trucks or insulated-tank railway cars, or in 10-gallon cans in the bunker-type refrigerated cars. In case the milk is shipped in tank trucks or cars it is usually cooled and stored in large insulated tanks ready for loading into the truck or car tanks as soon as they arrive. With tank trucks the milk is sometimes pumped direct from a cooler to the tank truck.

The milk should be delivered to the receiving station at a temperature not exceeding 50° F.; much of it, however, is probably about 60°. If the milk is delivered to the receiving station at 60° and cooled and stored at 35°, then, allowing four hours for the cooling operation and 20 per cent loss of refrigeration, when the milk is shipped immediately after cooling, the size of the machine necessary for handling 5,000 gallons of milk would be 25 tons if direct-expansion coolers are employed. In case the milk is held overnight in a cold-storage room, it would only be necessary to oper-

ate the machine for a short time additional for cooling the room, and no larger plant would be required.

If a brine-storage system is used and the machine is operated eight hours a day, the capacity of the machine should be 15.6 tons, allowing 50 per cent loss of refrigeration. A cubic foot of calcium chloride brine of a density of 1.2 and specific heat of 0.7 will absorb 52 British thermal units in rising 1° in temperature. Assuming that the machine is operating during the 4-hour cooling period and that the brine is allowed to rise from 15° to 30° F., the quantity of brine to be stored is 322 cubic feet.

Where a cold-storage room is provided for holding the milk at a low temperature in case of train delays, etc., either direct expansion, brine storage, or a combination of the two may be employed.

MARKET-MILK PLANTS

Market milk is milk that is sold for household purposes, and a market-milk plant is one equipped for processing, handling, and storing market milk. Nearly half the milk produced is used for household purposes. Such plants are located in cities and receive their supply of milk by trucks or trains, either direct from the farmers or from receiving stations. If the milk is not received at the city plant at a satisfactory temperature, it is rejected. In the majority of cases the milk is delivered to the plant by noon or before. It is then pasteurized, cooled, bottled, and stored overnight, and delivered to the customers early next morning. Processing the milk begins as soon as it is received, and the time required to pasteurize, cool, bottle, and store usually varies from 3 to 5 hours in the smaller and medium-size plants and from 6 to 8 hours in the larger plants.

Some of the largest plants that operate from six to eight hours per day in processing the milk store a considerable quantity of raw milk each day in insulated tanks to be used in emergencies such as delays in delivery due to storms or breakdowns in the plant. Such storage also enables the plant to start daily at a fixed time. Each afternoon, especially during the winter months, this reserve supply of raw milk is stored. This milk is cooled to a low temperature and stored overnight. It is pasteurized, cooled, and bottled next morning by the time delivery from the receiving stations begins. The greater part of refrigeration stored in the milk is regained through the use of a regenerator, or heat exchanger; consequently there is little loss from this source.

The hot milk from the pasteurizers flows into holding tanks. The greater part of the refrigeration required in a market-milk plant is consumed in cooling the milk as it comes from the holding tanks to the bottling machines. It is necessary either to install a refrigerating machine with sufficient capacity to handle the peak load, or to install a smaller machine, operate it for a longer time, and store up refrigeration for handling the peak load. Both methods are used. The refrigerating machine is operated also, of course, for cooling the storage room before the cooling of the milk is commenced and after the milk is cooled, bottled, and stored. This requires only a small part of the total capacity of the equipment.

In cooling the milk from the pasteurizing to the bottling temperature, usually a regenerator or heat exchanger is employed to transfer

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heat from the hot milk leaving the holding tanks to the cold milk entering the pasteurizer, thus economizing in both heating and cooling. Usually the temperature of the milk is reduced to about 90° F. at the outlet of the regenerator at which temperature it starts over the cooler. It is reduced to about 75° in winter and about 50° in summer over the water section of the cooler, and then to about 40° over the refrigerated section. At this temperature it goes to the bottling machine and is bottled. It is then stored in a refrigerated room overnight, in a temperature maintained at about 32° to 40°. Those companies that have a wide range of distribution usually cool the milk to about 35° over the cooler. Since the temperature of the bottles is usually about that of the air in the milk room, they raise the temperature of the milk a few degrees. This added heat should be removed overnight in the storage room.

The initial investment in a brine-storage system for a moderately large milk plant is considerable. The operation and maintenance of the brine circulation and storage equipment are also expensive. The initial cost of the larger refrigerating machine would be perhaps 25 per cent greater than that for the smaller one for the brine-circulation system, but the difference usually would be more than made up by the cost of the brine cooler, the brine-storage tank, and the brine pump. Power for operating the brine pump and for removing the heat generated in circulating the brine and absorbed through the surface of the brine cooler and pipes, is not required with the direct-expansion system. Furthermore, less power per ton of refrigeration is required in the direct-expansion system because a higher back pressure can be carried (p. 20). Power required per ton of refrigeration is usually from 25 to 30 per cent less for the direct-expansion than for the brine system. Also, the direct-expansion equipment occupies less building space, often an important matter in congested areas.

For a market-milk plant of 10,000 gallons capacity a complete direct-expansion system is the cheapest to install and the most economical to operate.

CREAMERIES

A creamery is a plant having for its primary object the manufacture of butter. At many plants only farm-skimmed cream is received, whereas at others whole milk is handled also. Some of the whole-milk plants are equipped to process milk and sell it as fluid milk or to make butter and manufacture condensed and dried skim milk and buttermilk.

When whole milk is received at a creamery, it is heated to a temperature between 90° and 100° F. and run through a cream separator to separate the cream from the skim milk. The cream thus obtained, also the farm-skimmed cream, is then pasteurized by heating it to about 150° and holding it at that temperature for 30 minutes, or by heating it to 180° or 190° for an instant. Usually the cream is then cooled immediately to about 40° and held for three hours or overnight before it is churned. Sometimes it is cooled to only about 68° held at that temperature for a few hours, and then cooled to 40°. After the holding period it is churned at a temperature of 45° to 55°. The temperature of the butter when removed from the churn is usually between 50° and 60°.

STORAGE OF BUTTER

The indications are that the lower the temperature at which butter is held, the better it will keep, but the expense of storing at very low temperatures for a short time is not often justified by the slight improvement in quality. For short periods of storage such as a creamery ordinarily would hold butter before shipping—say a week or 10 days—the temperature may be not higher than 35° F. But when butter is stored for several months, the temperature should be maintained at 0° or lower. Many large cold-storage companies hold it at −10°.

Satisfactory storage of butter requires not only a low temperature but also a relative humidity maintained at about 80 per cent. Such a humidity will prevent the growth of molds and will also prevent excessive drying out of the butter. When mechanical refrigeration is employed in cooling the storage room, the relative humidity usually is satisfactory, but with ice-cooled storage the relative humidity is generally high, and the moist air is favorable for the growth of molds. Ice-cooled storage for butter is therefore generally unsatisfactory, both because it is impossible to maintain temperatures sufficiently low to preserve the butter properly and because of the inconvenience of handling the ice and of the resulting slop and dampness and humidity.

Butter, like other dairy products, is very susceptible to odors of any kind and will readily absorb mold odors even if placed for a short time only in a damp and mold-infested room. Molds will grow readily on the containers and on the butter itself when stored in a damp room. The result is either a complete loss or a materially lower price.

It is evident from the foregoing that in the successful manufacture of butter refrigeration is necessary in every step of the process, and accurate control of temperatures is essential in the making of a high-grade product. In the modern creamery, refrigeration is employed in connection with the processes of pasteurization, ripening, and churning, in the preparation of starters, in cooling water for washing the butter, and in cooling the storage room for the finished product. Frequently it is employed in cooling the raw material.

CHEESE PLANTS

There are hundreds of varieties of cheese, for most of which refrigeration in some form is required in both manufacture and storage. Relatively few varieties, however, are made on a commercial scale in the United States.

In the manufacture of cheese the action of bacteria is employed and also, in some varieties, the action of certain molds. Both bacterial and mold growths are largely dependent on temperature and humidity conditions. In the manufacture of certain kinds of cheese the temperature and humidity conditions must be under close control for satisfactory results. At different stages of manufacture it is necessary to change both temperature and humidity in order that the proper growth of bacteria and mold may be obtained. Two of the most popular cheeses that depend upon both bacterial and mold action are now being made on a limited scale in this country, namely,

Camembert and Roquefort types made from cow's milk. In the manufacture of these cheeses temperatures and humidities play very important parts. The prevention of desiccation, oversalting and undersalting, proper growth of interior and exterior molds, satisfactory flavor and texture, all appear to be more or less dependent upon properly regulating the temperature, humidity, and ventilation.

In the curing of Roquefort cheese made from cow's milk, effort is made to maintain the conditions stated in Table 6. The cheese should be held at a temperature of 46° to 48° F. until consumed.

TABLE 6.—*Conditions favorable for curing Roquefort cheese made from cows' milk*

Period	Temperature	Relative humidity	Ventilation
	° *F.*	*Per cent*	
First week	65–68	85–90	Slight.
Second week	48–50	80–90	Considerable.
Third and fourth weeks	48–50	80–90	Do.
Second and third months	46–48	90–95	Moderate.
Fourth and fifth months	46–48	80–90	Considerable.

In the manufacture of Camembert cheese, it has been found desirable to maintain conditions as stated in Table 7. After the cheese is fully cured, a temperature of from 50° to 52° F. is advisable until the cheese is consumed. A considerable relative humidity probably would be 88 to 92 per cent, a moderate humidity 85 to 88 per cent, and a low humidity between 80 and 85 per cent.

TABLE 7.—*Conditions favorable for making Camembert cheese from uncut curd (according to Monteran)* [1]

Period	Temperature	Relative humidity	Ventilation	Mold development
	° *F.*			
First period, 4 days	50	Considerable	Very little	Starting of penicillium in acid medium.
Second period 10 to 12 days.	55–58	Moderate	Moderate	Development of penicillium in acid medium.
Third period, 2 to 4 days.	55	Low	Very active	Termination of the penicillium; the acid has disappeared, the medium, is alkaline, and the cheese becomes firm.

[1] MONTERAN, M. MONOGRAPHIC ET FABRICATION DU FROMAGE DE CAMEMBERT. 88 p., illus. Paris, 1908.

Desirable conditions in the manufacture of Swiss cheese are stated in Table 8.

TABLE 8.—*Conditions favorable for making Swiss cheese*

Period	Temperature	Relative humidity	Ventilation
	° *F.*	*Per cent*	
2 weeks in salt room	52–59	85–90	Moderate.
6 to 8 weeks in warm room	65–72	85–90	Do.
Cold storage	50–55	80–85	Do.

American or Cheddar cheese is cured for from 4 to 10 days at a temperature of 55° to 60° F., with plenty of ventilation. This allows the bacteria to develop properly. For long storage (4 to 12 months) it should be placed in a cold room at a temperature of from 32° to 35°. For short storage (two or three months) a temperature of 40° to 45° is satisfactory. When it is to be placed upon the market as soon as possible, it should be held at from 50° to 60° until it reaches a marketable condition.

CONDENSARIES

A condensary is a plant for concentrating milk by evaporating a part of the contained water. The evaporation usually takes place under vacuum. Refrigeration is employed to cool the product after it leaves the vacuum pan for storing. It is used also for holding the raw milk received at the condensary at a temperature of from 35° to 45° F. until it is to be processed.

Sweetened condensed milk contains sufficient cane sugar to preserve it. After leaving the vacuum pan it is cooled, either in ordinary milk cans set in cold water and rotated while stationary paddles keep the milk thoroughly stirred, in large tanks in which cold water or brine is circulated through coils immersed in the milk, or by running it through a countercurrent cooler in which cold water or brine is employed as the cooling medium.

The proper cooling of sweetened condensed milk is very important, for upon it depends to a great extent the smoothness of texture of the product. The rate of cooling from vacuum-pan temperature down through that of forced crystallization should be as rapid as practicable. The milk comes from the vacuum pan at from 125° to 140° F., and at this temperature is a saturated solution of milk sugar. As the temperature is lowered the solution becomes supersaturated, and the milk sugar begins to crystallize out. Should the rate of cooling be too slow, the crystals will be large and the texture of the milk will be coarse—what is known as sandy or gritty. With rapid cooling and agitation the crystals are very small, giving the desired smooth and velvety texture. Crystallization is slow at first but reaches a maximum rate at about 86°. From this point down to about 75° is the critical range through which forced crystallization is accomplished. Sometimes the rate of crystallization must be accelerated by adding a small amount of milk sugar, but ordinarily rapid cooling and agitation is sufficient to produce satisfactory results. The time required to lower the temperature through the range of maximum crystallization (86° to 75°) is from 15 to 30 minutes. Cooling should be continued to about 65°, at which temperature the milk should be barreled or canned. If intended for early consumption it need not be cooled below 65°, but if it is to be stored for a considerable period it should be kept at a temperature of 35° or 40°.

In addition to bacteria, milk contains yeast. The presence of yeast does not affect whole milk to any great extent, but in the case of condensed milk it is detrimental. The principal action of yeast is to form alcohol and carbon dioxide from the sugar in the milk. This action, however, is materially retarded at low temperatures, say 50° or lower.

Plain condensed milk, as the name implies, is simply the raw product concentrated by evaporation without the addition of sugar. When the proper concentration has been obtained, the milk is drawn from the vacuum pan and cooled at once, to approximately 60° F. if it is to be canned immediately. If it is to be sold in bulk it should be cooled to at least 40° and maintained at this temperature until used. It should never be allowed to freeze, as freezing would cause the separation of its constituent parts. Plain condensed milk is used largely by ice-cream and candy makers and by bakers, and since the demand is not always steady it is often necessary to hold it under refrigeration for a considerable time.

Evaporated milk is the term generally applied to sterilized unsweetened condensed milk. Since all bacteria and yeast spores are supposed to be destroyed by the application of heat in the sterilizing process, refrigeration would seem unnecessary. This result is not achieved, in all cases, however; therefore it is common practice, for long storage, to store the milk at a temperature between 35° and 40° F.

MILK-POWDER PLANTS

Milk powder is the product resulting from evaporation of practically all the water contained in the milk, thus leaving it in a powdered form. The finished product contains all the solids originally in the milk.

Refrigeration in the manufacture of milk powder is limited to storing the fresh milk in case it is not to be used immediately, and to storing the finished product. The fresh milk is held at a temperature of about 45° F. until used.

Between the temperatures of 68° and 86° F. it has been found that the oxidation of the fat in milk powder is comparatively rapid. Between the temperatures of 59° and 68°, however, the oxidation is somewhat retarded. The rate of oxidation at and below 59° has not been exactly determined, but experience seems to indicate that for any unsterilized product containing butterfat oxidation is materially reduced with the lowering of storage temperature. At the present time, milk powder commonly is stored at 35° to 40°. Owing to the hygroscopic nature of the powder, the storage room should be as dry as possible.

ICE-CREAM PLANTS

In the manufacture of ice cream, refrigeration is employed in cooling the mix after pasteurization, in holding the mix, and in freezing and hardening it. It is also used in storage of materials, in distributing the ice cream to retailers, and in holding low temperatures in the retail cabinets. In other words, refrigeration is necessary at every stage of the manufacture and distribution of ice cream from the preparation of the mix to final consumption, and at no time can the temperature approach the melting point of the product without materially injuring its quality.

The mix is first pasteurized as a safeguard to health, to check any fermentation, and to destroy most of the bacteria as a basis for regulating the time and temperature of storage. From the pasteurizer the mix usually is put through a homogenizer or viscolizer to break up the fat globules and give a greater dispersion of the butterfat,

which results in an increased viscosity and an improved body and texture to the cream. From the homogenizer or viscolizer the mix goes into the storage vats.

When the mix is delivered into the aging vats it is immediately cooled and is then held at a temperature of between 35° and 40° F. for from 24 to 36 hours. The aging usually is done in a special type of vat that keeps the mix stirred and thus prevents the settling out of the heavier ingredients. The aging or holding of the mix, if properly done, increases the viscosity and texture of the mix and assists in obtaining and maintaining the proper swell or overrun. During the storage period there is an increase in the acidity of the mix, but this increase will be slight if the holding takes place at a temperature below 40°. The process requires careful watching and control of temperatures in order to prevent overripening, which causes the mix to become sour and unfit for ice cream.

The swell, or overrun, is the increase in volume of the ice cream during the process of freezing. It is due in part to expansion of the ingredients of the mix, but mainly to the incorporation of air by the beating or whipping action of the freezer dashers. The amount of swell in the final product depends upon the rate of freezing, the whipping action of the dashers, and the conditions of hardening the cream. The desired swell for plain ice cream and for fruit creams is approximately 100 per cent. A proper amount is very important; insufficient swell will cause the cream to be heavy, soggy, and unpalatable, while too much swell will cause it to be fluffy and more or less grainy and brittle.

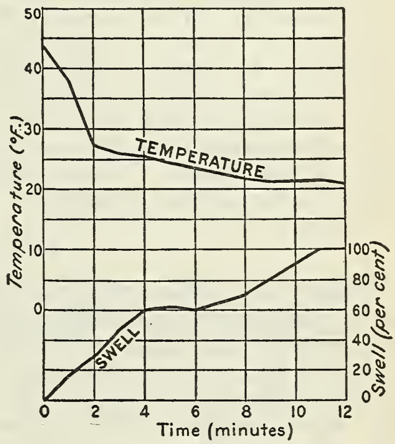

FIGURE 31.—Typical curves of temperature and swell in freezing ice cream

FREEZING

Before the mix is put into the freezers, they are cooled by running the refrigerant through them for a few minutes. Then the mix, suitably chilled and with flavors added, is run into the freezers, and the whipping is commenced. The time consumed in freezing and whipping is usually about 10 to 15 minutes. It varies, being dependent upon the temperature maintained in the freezer, the speed of the dasher, the composition of the mix, and other conditions. The curves in Figure 31 show the condition existing in an ice-cream freezer during the process of freezing.

It is important that the mix enter the freezer at a temperature of approximately 40° F. in order to eliminate, as far as possible, the danger of churning and producing a cream of greasy texture. The sensible heat of the mix is removed in about four minutes, and freezing commences at about 29°, that is, ice crystals begin to form at about this temperature. Through the latent-heat zone the temperature drops somewhat, as shown in Figure 31, due to the con-

centration of the sugar content. While the flattened portion of the temperature curve is generally referred to as the latent-heat zone, it should be remembered that latent heat is extracted throughout the freezing process, even in the hardening room. In passing through the latent-heat zone, air is incorporated by the whipping action of the dashers, and the desired swell is obtained. The product should be drawn promptly when the desired swell has been obtained, for the water content freezes rapidly at the end of the latent-heat zone. If the whipping and freezing is continued, the swell will be decreased, but if the whipping is continued with the refrigerant turned off, the swell will be increased. Should the swell exceed 100 per cent, it can be whipped down to the desired volume by continuing the whipping for a short time with the refrigerant turned on.

The temperature of the refrigerant used for freezing by different manufacturers varies widely from −10° to +14° F. Freezing temperatures of from −5° to +5° are used most commonly by manufacturers. Ice cream is composed largely of ice crystals, and the size of these crystals determines the smoothness of the product. Since it takes time for the individual crystals to grow, quick freezing serves to minimize the size of crystals and hence increases the smoothness of the cream. Consequently shortening the freezing time results in an improved quality.

BRINE FREEZERS

When brine is the refrigerant, the volume supplied to the freezers is very important for satisfactory and economical freezing. If the movement of the brine over the heat-transmitting surfaces is slow, the mean temperature difference between brine and ice cream may be too small even though the initial temperature of the brine is low. The flow should be sufficiently rapid to sweep off quickly the warm film of brine from the heat-transmitting surfaces. On the other hand, if the velocity of the brine through the freezer is too rapid, additional power is required for operating the pumps at a relatively high pressure, and that power is converted into heat which warms the brine and must be removed by additional refrigeration.

The volume of brine passing through the freezer should be sufficient to absorb the heat from the mix with only a moderate rise in temperature. The difference in temperature between the inlet and outlet brine should not exceed 5° F., and the volume of brine circulated per minute through the freezer should be approximately twice the rated capacity of the freezer; that is, through an 80-quart freezer 40 gallons of brine per minute should be circulated. This will give a difference of approximately 4° F. between the inlet and outlet brine, under average conditions.

The temperature and the volume of brine circulating through a freezer should be constant to produce a uniform product. A variation in pressure and therefore in volume of the brine may be caused by stopping or starting different freezing units or by varying the rate of flow through different freezers. Therefore arrangements should be provided for maintaining a constant pressure in the brine feeder lines at all times. This usually is accomplished by installing

between the supply and the return mains, beyond the battery of freezers, a spring-loaded relief valve adjusted to maintain the required pressure. This will give a constant flow of brine through the freezers regardless of the number in operation.

The sizes of brine mains and branches should be such that the velocity of brine will not exceed 150 linear feet per minute. At a velocity greater than this the cost of additional power for operating the pumps usually overbalances the gain in initial cost of the smaller piping.

Every ice-cream plant should be equipped with duplicate brine pumps, each of ample capacity to handle the maximum quantity of brine that will be required. The pumps should be connected in parallel, and so valved that in case one breaks down the other can quickly be put into service. Since the brine pressure generally is low, the centrifugal pump gives the best service, is cheaper, and occupies the least space.

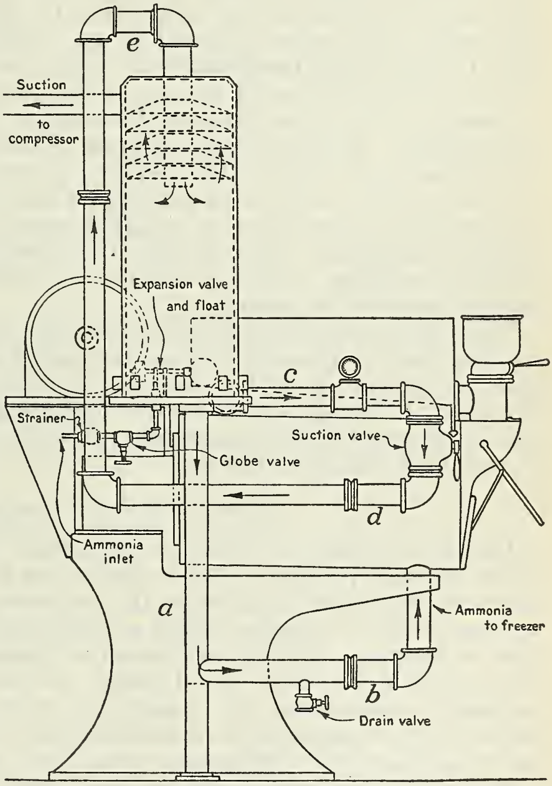

FIGURE 32.—Direct-expansion batch ice-cream freezer

DIRECT-EXPANSION FREEZERS

In the past few years ice-cream freezers have been designed in which the cream is frozen by direct expansion of ammonia in the freezer. In this type the liquid refrigerant is applied automatically, and the temperature is kept constant by controlling the evaporating pressure or the flow of liquid ammonia. One method of accomplishing this control with batch freezers is by means of a combination float valve and accumulator shown in Figure 32.

The float accumulator is constructed as indicated by the dotted lines in the figure, with the float valve in the base or lower portion and the accumulator baffles immediately above. The liquid ammonia before being admitted to the shell through the float valve passes through a liquid strainer to remove any foreign substance that might prevent the valve from seating properly. When the liquid reaches a predetermined level in the shell, which is such that it will

give complete flooded operation of the freezer, the float rises and closes the valve, opening again only when the liquid level drops below this point. The liquid, in passing from the float accumulator, is carried down through the pipe *a* which serves the double purpose of liquid line and support, thence through pipe *b* entering at the lowest portion of the freezer.

The suction or return gas is taken off at the topmost part of the freezing chamber, a necessity in flooded circulating systems, and carried through pipes *c*, *d*, and *e* into the upper portion of the float accumulator. The pipe admitting the gas to the accumulator extends downward through the baffles. Thus the gas must pass upward over the baffles, where any possible slugs of liquid ammonia that may have been carried over from the freezer are removed and returned to the body of liquid in the lower portion of the shell. This prevents any possibility of "slop over" of liquid ammonia which must be prevented if compressor troubles are to be avoided.

Direct expansion has been applied also to the continuous freezing of ice cream. In the continuous type of freezer, the mix is pumped to the freezer by a specially designed pump that delivers with the mix the requisite amount of air to give the desired swell. The mix is forced in a thin layer at a high pressure and velocity over the freezing surfaces; consequently the freezing takes place very quickly, resulting in the formation of minute ice crystals and a smooth-textured ice cream.

With direct-expansion freezers the brine tanks and brine pumps are eliminated. This saves the space that would be required for the brine equipment, as well as the cost of buying and operating them. Moreover, freezing can be started immediately without waiting to cool brine, and the direct-expansion freezers are more economical to operate than the brine freezers.

POWER TO DRIVE THE FREEZER

The power required to drive an ice-cream freezer increases rapidly as the freezing progresses; that required at the end of the process is about ten times that required at the beginning. This increase in the amount of power required offers a convenient means of judging the state of freezing. By the installation of a suitable watt meter in the motor circuit, the time for drawing off the frozen cream can be accurately determined by noting the power consumption. This method is now employed to a considerable extent. The point on the meter at which the refrigerant should be cut off, however, should be determined experimentally for each particular installation.

HARDENING

Except in the case of the low-temperature or quick-hardening process, about half of the actual freezing of the ice cream takes place in the hardening room. The temperature of the ice cream as it comes from the freezer ranges from 23° to 27° F. At this temperature the incorporated air will not be retained for any considerable length of time, as the cell walls inclosing the air are not sufficiently rigid. The partly frozen ice cream is therefore quickly transferred from the freezer to the hardening room, where its temperature is lowered.

The containers for the ice cream should be at a temperature lower than that of the ice cream as it comes from the freezer; otherwise there will result a thin layer of melted ice cream in contact with the sides of the containers which, on being again frozen in the hardening room, will produce coarse ice crystals. The quicker the ice cream is frozen in the hardening room, the smoother it will be and the better will it retain the swell.

Here again practice varies widely in the temperatures maintained in the hardening room. They range from $-15°$ to $+10°$ F. Since about 50 per cent of the water content is frozen in the freezers, there remains about 50 per cent to be frozen in the hardening room. All the water content, however, is never frozen in practice on account of the sugar-protein magma, which has the property of retaining a certain quantity of water in the liquid state even when reduced to very low temperatures. The greater portion of the water, however, must be frozen in a comparatively short time in order to produce and maintain a smooth texture in the ice cream. A temperature above 0° is too high for best results. The consensus of opinion of ice-cream manufacturers is that the hardening room should be maintained at about $-10°$ for best results.

At the present time the still-air method of cooling hardening rooms is almost universally employed. That is, the room contains the required amount of direct-expansion pipe, usually arranged to provide racks or shelves for carrying the cans of ice cream, and no provision is made for forced circulation of air in the room. In still-air hardening rooms it takes at least from 18 to 24 hours for the ice cream in the center of the regulation 5-gallon can to approximate the temperature of the hardening room.

On account of the cost of producing refrigeration at the low temperatures required for the proper hardening of ice cream, to the need for steady temperatures, and to the necessity of holding low temperatures for considerable lengths of time in case of breakdowns to the machinery, the hardening rooms should be provided with ample insulation. There should be no hollow spaces in walls, floors, or ceilings, for such spaces permit the collection of moisture and frost and thus cause weakening and deterioration of the structure. The structural walls should, therefore, be of solid construction such as brick or concrete. Practice seems to indicate that at least the equivalent of 8 inches of pure cork board should be used in the floors of the hardening rooms where the room temperature is maintained at $-15°$ F., and of 10 inches of cork board where the room temperature is to be held at $-20°$. The instructions and cautions given on pages 14 and 23 should be observed with particular care in building these rooms.

LOW-TEMPERATURE HARDENING

The latest development in the hardening of ice cream consists in subjecting the cartons of ice cream to a very low temperature, from $-35°$ to $-55°$ F., for a period of 30 to 60 minutes. The usual arrangement consists of an endless chain conveyor carrying the cartons of ice cream through an insulated tunnel some 40 or 50 feet long, through which a continuous blast of cold air is blowing in the opposite direction. The conveyor is equipped with variable speed

drive, so that the time of exposure to the low temperature can be regulated. With the air-blast system, the hardening process is much more rapid than if natural air circulation is employed, and higher temperatures can be employed for the same results. Tests have shown that this arrangement will cool packages of ice cream 2¾ by 2¾ by 4¾ inches to a temperature of 0° at the center in about 45 minutes, with an air-blast temperature of −35°. After the ice cream is hardened in the low-temperature tunnel, it is stored at a temperature of about 0° until used. For economical operation, the low-temperature tunnel should be located in the storage room.

While it is possible to use ammonia machines for the low-temperature hardening of ice cream, better results are obtained with carbon dioxide (CO_2) machines, because with carbon dioxide the suction pressure is from 75 to 100 pounds per square inch, whereas with ammonia a high vacuum is necessary. Usually a combination is employed by using the carbon dioxide machine for producing the low temperature and an ammonia machine operating on the condenser of the carbon dioxide machine. The condenser pressure of the carbon dioxide machine is thus maintained at about 350 to 450 pounds per square inch. However, the power requirement increases rapidly and the capacity of the machine decreases rapidly with the lowering of temperature. Consequently, hardening temperatures much below −35° F. are likely to be impracticable due to the large initial cost of the plant and the high cost of operation.

CAPACITY OF REFRIGERATING MACHINE

The physical properties of ice cream vary with the composition of the mix, but in computing the heat to be extracted from flavored ice cream the following figures may be used:

Specific heat of mix		0.80
Freezing point of mix	degrees Fahrenheit	26
Latent heat of freezing per pound	British thermal units	90
Specific heat of frozen ice cream		.45
Weight of a gallon of mix	pounds	9
Weight of a gallon of ice cream of 85 per cent swell	do	4.86

If the mix enters the freezer at 45° F. and is cooled in the freezer to 26° and in the hardening room to 0°, the total heat removed from each gallon of ice cream weighing 4.86 pounds is 568.1 British thermal units.

Ice cream containing fruits or nuts weighs about 6 pounds per gallon, and the actual refrigeration required for freezing and hardening is 701.4 British thermal units per gallon.

Unavoidable refrigeration losses, due to heat absorbed from the surrounding air during the freezing and the transfer to the hardening room, are approximately equal to the refrigeration required by the ice cream itself, so the heat required to be extracted by the machine is, for flavored ice cream, 1,137 British thermal units, and for fruit and nut ice cream 1,404 British thermal units per gallon.

The capacity of a refrigerating machine as recommended by different manufacturers for an ice-cream plant of a given output varies widely. Some manufacturers estimate on the basis of only 200 British thermal units per pound of ice cream, to cover all stages of the

process. Some estimate 1 ton of machine capacity for each 100 gallons of ice cream manufactured daily, with 12 hours operation of the machine, and others estimate 1 ton capacity for each 60 gallons of average daily output in peak seasons with the machine operating half the time. For all purposes, including manufacture of ice used in delivery and care of the ice cream after it leaves the plant, some estimate that 1 ton of refrigerating capacity is required for each 21 gallons of average daily output in the peak season.

While rule-of-thumb methods may be helpful for quick and rough estimating, they should never be used for final determination of the size of equipment. Since practically no two ice-cream plants operate exactly alike nor handle their raw and finished products in exactly the same way, no one size of refrigeration machine will give adequate and economical refrigeration for a plant of a given capacity under all conditions. For each plant, the refrigeration requirements should be computed carefully by some one thoroughly familiar with refrigeration and also familiar with the processes employed in the manufacture of ice cream, who will consider the quantity of product, the method of operating the equipment, the manner of handling the raw material and the finished products, and the local conditions and requirements.

SOLID CARBON DIOXIDE

In the transportation of dairy products, especially ice cream, solid carbon dioxide has come into prominence recently. The characteristics that have induced the use of this substance are its absolute dryness, its low temperature, its larger refrigerative effect as compared with water ice, and the insulating effect of the gas formed.

The dryness of carbon dioxide ice is due to the fact that it sublimes; that is, the ice evaporates into gas without apparently liquefying. Therefore it is possible to employ simple cardboard cartons for packaging perishable products for transportation. The temperature of sublimation, under atmospheric pressure, is about −109° F. In contact with the skin, the ice produces burns similar to those made by a hot iron, therefore it never should be handled with bare hands. The refrigerative effect of carbon dioxide ice at 32° is, per pound, approximately twice that of water ice.

The value of this substance as a refrigerant is due in large measure to the low heat conductivity of the gas formed as the ice sublimes. This gas is evolved rapidly and, being heavier than air, displaces the air in the package and surrounds and submerges both the refrigerant and the product being refrigerated in an insulating bath of cold gas. Therefore, in packing the ice and the product, a space should be provided between the product and the walls of the container, and the refrigerant should be placed at the top.

BRINE ICE

The principal use of frozen brine is for holding temperatures in retail ice-cream cabinets, refrigerated counters, and refrigerator trucks. While the cooling effect stored in frozen brine is less per pound than in water ice, the melting point, at which it absorbs its latent heat, is much lower than that of water ice and, hence, much

lower temperatures can be obtained with the brine ice. The freezing and melting point depends upon the concentration of the brine, and the salt and water are proportioned according to the desired melting temperature. The proportions of salt and water usually employed are such as to give a melting temperature of about 0° F., and ordinarily the frozen brine is cooled to −10° or −15°. Special triangular cans about 18 inches long are commonly used. They are filled with the brine, which is frozen and subcooled in a low-temperature room.

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